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ENVIRONMENTAL IMPACTS OF TORREFIED WOOD PELLET PRODUCTION

Cases Rislog and Pursiala pilot plant

Julkaisu 7 / 2012

30.11.2012

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PUBLIC**Title**

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Abstract

There is a clear demand for cutting the greenhouse gas emissions and increase the share of the renewable energy sources in energy production. Wood torrefaction, heat treatment method for refining the wood fuel enables the wood utilisation in existing coal-fired power plants. The method is relatively new in bioenergy production, but it enables the large-scale utilisation of wood-based fuels without significant technical investments.

There is an initiative to build up a commercial scale torrefaction plant in Ristiina, Southern Savonia. The technology will be tested in advance in pilot scale, in which the raw material properties and end product suitability for current coal-fired power plants will be tested. The pilot plant will be built in Pursiala, Mikkeli. Both of these projects are run by Miktech Ltd. / Biosaimaa-cluster. The aim is to start building the pilot plant still in 2012, and the commercial scale plant is planned to be in operation in 2015.

This study concentrates on the environmental impacts and environmental risk assessment of both of the plants. Neither of the plants existed at the time writing the study, and thus the environmental impacts are rather estimations. However, the probable equipment suppliers of the pilot plant have been consulted, as well as other experts and technology developers of the field. The equipment supplier of the commercial scale plant, "Rislog", is not chosen yet, and thus the impact assessment is done on the basis of the expected impacts of the pilot plant.

According to the environmental impact analysis, the environmental impacts of torrefaction plants are not intolerable, and when considering the big picture - replacing fossil fuels by wood-based energy sources - the total impacts are rather positive. Naturally there are some local impacts of the plants (noise nuisance, dusting, and occasionally malodorous gases), some emissions to air (CO, CO₂, and NO_x) and emissions of transportation. However, replacing coal by torrefied wood pellets, decreases the total CO₂ emissions, decreases the demand of imported energy sources and enhances local economy.

Keywords

torrefaction, Rislog, piloting, torrefied wood pellets, bio-logistic centre, Biosaimaa

Pages

73 + 2

Language

English

Date of the publication

30.11.2012

Remarks (notes of appendices)**Project**

Centre of Expertise Programme / Forest Industry Future

Funding

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1 INTRODUCTION

Wood is one of the most traditional energy sources. However, due to the targets to increase the utilisation rate of renewable energy sources, development of more efficient ways for energy utilisation of wood is required. Torrefaction is a new technology for wood refinement, and the end product, i.e. the torrefied wood pellets, can be utilised in existing coal-fired power plants. There is an initiative to build a large-scale torrefaction plant in Ristiina, Eastern Finland, so that the torrefied wood pellet production could start in 2015. Because of the technological novelty, the technology will be tested first in a pilot torrefaction unit, which is about to be built in Pursiala power plant area in Mikkeli, Eastern Finland. The project is coordinated by Miktech Ltd., the technology and innovation centre of Mikkeli. This study concentrates on the environmental impacts of the torrefaction plant, and both the pilot and the large-scale unit are surveyed in detail. In terms of this project, several studies have been conducted previously, and thus this report will not consider some aspects, such as the technology as such or the raw material supply, too deeply. The aim is to estimate the possible environmental impacts as well as possible environmental risks in a situation where no other similar plants yet exist.

This study was done as a BSc thesis for Biosaimaa-cluster, which is the bioenergy development programme coordinated by Miktech Ltd. Ristiina bio-logistic centre, “Rislog”, and its torrefaction plant project is one of the key projects of the Biosaimaa-cluster. Several companies have been involved in the planning process of the commercial scale plant and the Pursiala piloting plant of the torrefaction technology, and they have also been of great help in terms of this thesis. In the following chapters, we first deal with the background on which the development of torrefaction technology is based as well as the legislative framework of biofuel production in Finland. The following section contains the theoretical bases of the environmental impact and risk assessments. Furthermore, the torrefaction process and the production chain of torrefied material are discussed. Despite the chapter about the existing torrefaction plant in the Netherlands, these chapters cover torrefaction in general level. The latter part of the study, being the environmental impact assessment, is organised by the production chain of the torrefied wood pellet. The first steps of the production chain, which are common for both the Pursiala pilot and Ristiina large scale torrefaction unit, are discussed jointly. Both projects and the environmental impacts caused by them as well as the environmental risk assessments are discussed separately due to the remarkable differences in the scales and natures of each project.

2 DEMAND FOR RENEWABLE ENERGY SOURCES

Sunlight is mainly short wavelength radiation that passes through the atmosphere easily. When reaching the ground, the radiation energy transforms partly into longer wavelength thermal radiation. Thermal radiation does not pass the atmosphere as easily as the shorter wavelength radiation light and thus the generated heat cannot escape back to space and stays in the atmosphere. This is the basic principle of the phenomenon called greenhouse effect. The greenhouse gases (GHG's), i.e. the gases that promote the greenhouse

effect, namely carbon dioxide (CO₂), methane (CH₄) and nitrous oxide (N₂O), increase the atmosphere's ability to hold the thermal radiation. When the amount of GHG's in the atmosphere grows, the amount of thermal energy in the atmosphere also increases and thus the climate warms up. One of the main reasons behind global warming is the constant increase of fossil fuels utilisation and the changes in land use, namely the increase of the built area. (Kareinen et al. 2008.)

Reduction of GHG emissions is essential in order to fight global warming. Increasing the energy production by renewable means reduces GHG emissions, but only if fossil fuels are replaced. European Union (EU) has set directive for the promotion of the use of energy from renewable sources (2009/28/EC). The directive determines the so called 20-20-20 targets for year 2020. It means that the aim is to reduce greenhouse gas emission levels by 20 % from the GHG emission level of year 1990. The goal is distributed to the member states unevenly, so that all the nations participate on the emission reduction according to their capability. As an example, Finland's target is to reduce its emissions by 17 % of the year 2005 emissions. The energy consumption is targeted to be 20 % less than estimated according to the normal development. The third goal is to increase the share of renewable energy sources to 20 % of total energy production in the EU area. However, the Renewable Energy Directive has flexibility in green technology mix, by which the aim of 20 % share is achieved. Bioenergy is about to increase its importance, and it is also strongly involved in the EU 2050 energy roadmap. This requires, however, the development of sustainable ways to utilize the renewable energy sources. (Langue 2012.)

At the moment, coal is one of the most significant energy sources globally, and contributes more than 40 % to the world's electricity production. Increasing the co-firing of biofuels in existing coal-fired power plants would require a huge amount of processed biomass. It is reported that co-firing of torrefied biomass at the rate of 10 % in 10 % of all coal-fired power plants would require 33 million tons of torrefied fuel. (Schaubach 2012.) It is clear that the long-term goals of biofuels cannot be achieved unless sustainable refinement ways are developed. In Finland, because of the high forest energy potential, wood-based energy can be utilized sustainably, without causing remarkable CO₂ emissions during its growing, harvesting and refining. In order to cut the GHG emissions, wood is a good option for fossil fuels because of its carbon neutrality. (Kuusinen & Ilvesniemi (ed.) 2008.) Wood also provides potential for large-scale bioenergy production.

Renewable energy production targets and obligations, together with the carbon dioxide emission trade, drive the transition to a cleaner energy production system. One of the most promising ways to meet the energy targets is biomass co-firing, and for this reason the cost-effective solutions for co-firing are currently being developed. (Wolfgang 2012.) Meeting the 20-20-20 targets by 2020 would require fast growth of wood-based bioenergy sector in Europe (Teräs 2012). Building up totally new power plants would be expensive and non-eco-efficient, and thus it is wise to develop renewable energy sources that could be utilised in existing power plants. However, the existing plants are often designed to use only a specific fuel, and implementing another energy source is not typically possible without technical modifications. Still, even with investments in dedicated biomass handling and processing equipment, the co-firing rate of biomass in mainly coal-fired plant is limited to maximum of 20 % because of different physicochemical properties. (Wolfgang 2012.)

3 ENVIRONMENTAL PERMIT POLICY AND ENVIRONMENTAL IMPACT AND RISK ASSESSMENT

3.1 Environmental permit policy

In Finland, the environmental permit policy bases on the Environmental Protection Act (86/2000) and Environmental Protection Decree (169/2000). Environmental permit is required for functions that may cause environmental pollution. The specifications of the operation, expected emissions of it and the ways to reduce them are described in environmental permit application. The requirement for gaining the environmental permit is that the operation must not cause health problems. (Ympäristölupa 2012.) A main objective of the Environmental Protection Act is to prevent the environmental degradation comprehensively. Law obligates the operator to consider the probability of environmental damage due to the operation, the risk of accidents and the ways to prevent and restrict the negative environmental impacts. Environmental legislation bases on the precautionary principle, according to which all possible risks should be prevented, and thus the operator should be aware of all the potential environmental risks of the operation. Many of the industrial fields and their special features are covered in the legislation separately, and specific regulations are given for their processes. Some general principles are also given, and for example according to the Environmental Protection Act (86/2000) § 47, if the waste water is taken to a municipal waste water treatment plant, the pre-treatment requirements have to be determined in advance, if it is needed. The spoilage of the ground and water system is prohibited in all cases. (Wessberg et al. 2000.)

Environmental permit is required for an industrial plant that produces solid fuel over 3 000 t/a. In the permit application, information about the planned process and expected pollutants and their effects to the nature has to be described in detail. According to the Best Available Techniques (BAT) principle, the best available techniques have to be implemented in order to diminish the energy and resource consumption and reduce the waste production. (Environmental Protection Decree 169/2000.) However, it must be pointed out that the emission levels reached by following the BAT principle are not the permit limits and although the BAT principles are followed, it is impossible to have best result values in all emission categories and yet produce a competitive product (Nilsson et al. 2007).

According to Environmental Protection Act (86/2000), in case of temporary experimental activity where the operation level is lower than the limit value of environmental permit policy and the permit is not thus needed, the announcement for environmental authorities is required in cases where the operation will cause noise or quaking. The experimental activity can be for example a demonstration of a technical implementation or preparation of environmental protection investment. The operation is considered temporary, when the experimental activity lasts no longer than 18 months (Panula-Ontto-Suuronen 2012a). The announcement is given written and it includes the information about the process itself, the used raw materials, the expected emissions and their impacts and the inquest of the planned environmental protection activities. It must be handed at least 30 days before starting the operation, but according to Panula-Ontto-Suuronen (2012a), in practise more time is needed, especially if the environmental au-

thorities need to consult other authorities before giving the permit to start the operation. The announcement procedure is not required from operations that are involved in environmental permit process.

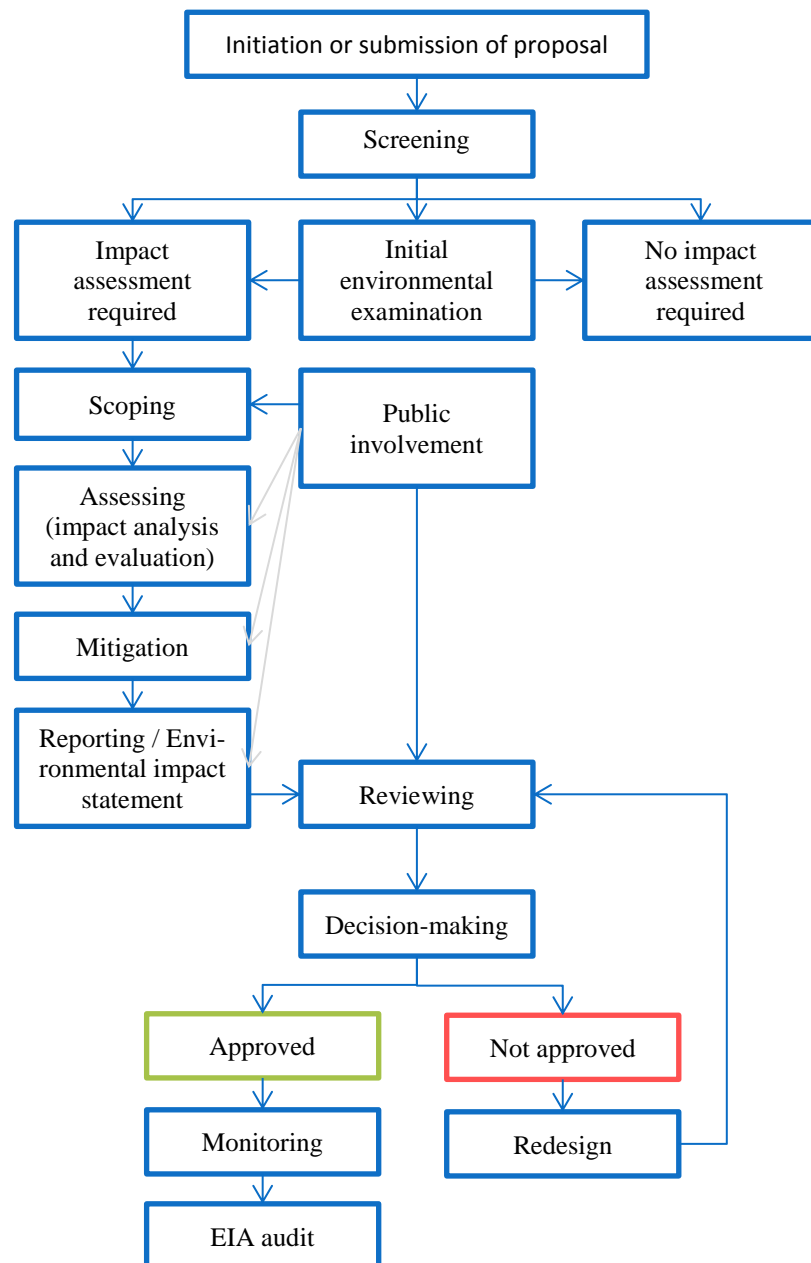
Environmental impact assessment (EIA; “YVA-procedure” in Finnish) is a wider procedure than the announcement practise, and is used for ensuring that the environmental impacts are studied in sufficient detail in the environmental permit procedure. The EIA procedure is based on regulating EU directives and other international conventions and protocols. Environmental impact assessment of projects is regulated by the Act on Environmental Impact Assessment Procedure, which determines the types of projects for which the procedure is required. In general, these are projects that may have harmful impacts on human health, the natural environment or biodiversity and natural resources, the landscape or the built environment. In practise, the Centre for Economic Development, Transport and the Environment (“ELY Centre”) interprets whether the EIA procedure is required for the project. The procedure integrates the environmental consideration into planning process, and the aim is to prevent, or at least reduce, the harmful environmental impacts well in advance of the operation. All the parties, on which the project may affect, can participate on the process. EIA is a tool of the planning process, and its results have to be considered in environmental permit consideration. The party behind the project is responsible for composing the environmental reports required. (Finnish Environment Institute 2012a.) The environmental impacts of a single project can also be assessed in the land use planning process, and if the parties affected by the operation are already heard during that process, the EIA process is not necessarily required (Finnish Environment Institute 2012b). The EIA procedure is dealt more in detail in the following chapter.

The legislative framework in Finland is ideal for biomass pellet markets, since both favourable legal conditions and available support options exist in all small, medium and industrial scales. Similar conditions are at the moment prevalent only in Sweden, in industrial scale also in Denmark, but in other countries in Europe either legal conditions or support options availability is not the best possible. (Zeng 2012). Environmental impacts of the biomass refinement plant can be assessed in the land use planning process, and if a public hearing is organized, the EIA procedure is not necessary. The EIA procedure itself will not add value to the project, and thus well done land use planning and good research work can give the same result (Panula-Ontto-Suuronen 2012a).

3.2 Environmental impact assessment

Environmental impact assessment (EIA) is an evaluation of the impacts that may arise due to some action or operation and that has a significant effect on the natural and man-made environment. In principle, it should lead to abandonment of environmentally harmful actions and substances. It must be pointed out that the purpose of the EIA is not to prevent the actions with harmful environmental impacts from being implemented, rather the idea is that they are authorised in the full knowledge of the environmental impacts. The EIA procedure consists of several iterative steps. The screening of the process determines whether an EIA process is required in a particular case. A single operation will not necessarily require EIA procedure, and the process as whole determines the need. If EIA is required, the alternative means of achieving the objectives are considered, and the selected proposal is designed. If not the whole process, an EIA can cover only some topics.

Deciding on the topics to be covered is part of scoping. The EIA report represents the alternatives and the estimated impacts and their significance. The mitigation of environmental impacts should be involved in each stage of the process. When ready, the report is reviewed to ensure its adequacy. The EIA report is used in making of the proposal. If implemented, the impacts of the proposal are monitored. The EIA process is cyclical, and thus the process may return back to some stage, and some steps do not necessarily take place at all in some EIA systems. (Wood 1995.) The process is illustrated in Picture 1.



Picture 1 The EIA process

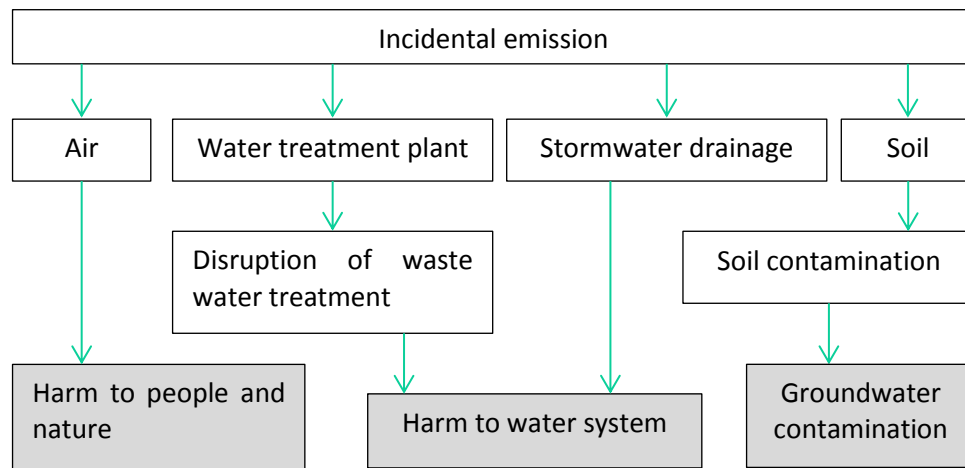
As seen from Picture 1, public involvement is one of the key features of environmental impact assessment process. Publication is decreed in the Act on Environmental Impact Assessment Procedure (468/1994). Ideally, public participation should take place in each step of the process, but at least in programme scoping and reviewing stages the public

hearings are arranged. At these stages, organizations, other authorities or basically anyone can leave notes on the process; the project is open for comments for 30 - 60 days.

3.2.1 Environment and the emissions

In terms of a company, environment is all that surrounds it. Thus it covers the surrounding areas including the buildings and natural elements, but also the people and other living organisms. On the other hand, the environment can be divided into internal and external ones, the internal environment consisting of the buildings, machines and personnel of a company. In some cases also the customers, owners and subcontractors can be seen as elements of the company's internal environment. Furthermore, the environment can be seen as a combination of the nature and the cultural environment, on both of which the environmental impacts of the company are directed. A company can have several optional environmental strategies, and its approach on environmental issues can either be defensive, passive, reactive or proactive. Preparing on the environmental hazards is important because unplanned, unpredictable and usually great-in-volume incidental emissions cause remarkable damage on the environmental reputation and image of a company. When there is information about the environmental risks, provided by systematic environmental impact analysis, then the stakeholders can be informed in adequate level, in advance and in case of a hazard. (Wessberg et al. 2000.)

Wessberg et al. (2000) determine emission to be the release of a matter, energy, heat, radiation, light, vibration, smell or noise into air, water or soil. Emissions can be continuous or occasional and they can also be something that is not automatically considered to be disruptive. Emissions can be distributed to the environment via several paths depending on their nature and source. They can either be gaseous compounds, which are released into the atmosphere, or solid or liquid, which are spread into water system or ground, see Picture 2. Emissions can also be carried from material to another, e.g. from soil to ground water. The incidental emissions are caused in situations of disorder or accident, and thus are unpredictable and unplanned. Emissions and environmental hazards bring out the need for environmental protection. Market derived needs for environmental protection affect the company's image; operational ones are the needs to ensure the unhindered production. Normative needs are the needs to follow the legislation and other requirements, and ethical perspective to environmental needs consider the moral and ethical approach. Incidental emissions relate to all of these categories, and thus the management of the accidental emission risk is very important. Due to the technical development, the continuous emissions can be controlled efficiently, and thus the significance of the control of the incidental emissions is emphasised when analysing the total emissions of a company. Control of the environmental protection initiatives is called environmental management. (Wessberg et al. 2000)



Picture 2 The emanate of accidental emissions into nature (see e.g. Wessberg et al. 2000)

The introduction of the emissions on the environment described in Picture 2 is approximate, and describes some general scenarios of incidental emissions. The possible pathways to the nature are essential to understand in order to cut the access of the emissions into them. Environmental impact assessment helps in this kind of process, and provides a systematic basis for environmental impact analysis.

3.2.2 EIA system

According to Wood (1995), the features of the effective environmental impact assessment are the contribution of the information generated in the process to decision making, and acceptance of the proposals for objectives of environmental management. Also, if the predictions of the effectiveness of impact management measures are accurate, the EIA has succeeded. The efficiency of the process can be evaluated by the timely relative-ness of the EIA decisions to economic and other factors affecting the project decisions, and the reasonability of the costs of the process. The process can be considered fair, if all the stakeholders and parties interested in the project have an equal opportunity to participate on the decision making and influence the decision before it is made, and the people affected directly by the project have equal and fair compensation. Since, in practise, all the EIA systems are unique and particular set of legal, administrative and political circumstances affect the system. Thus the EIA systems should be analysed in their international context, which may explain its nature more deeply, and the analysis across EIA systems enables better understanding practise in any particular jurisdiction.

3.2.3 Environmental management

The Eco-Management and Audit Scheme (EMAS) is a voluntary environmental management system for the private sector and the public administration on environmental impacts. It points out the environmental impacts to be considered in terms of environmental management system. These are controlled and uncontrolled emissions to the atmosphere, water system and ground, solid and other waste, especially the hazardous ones, soil spoilage, utilisation of soil, water, fuels, energy and other natural resources, thermal energy, noise, odour and dust emissions and caused vibration and visual harm, and the

impacts to the special sites of nature and ecosystem. In terms of incidental emissions, especially the impacts that are caused by unusual operation conditions or disturbance, accident or any emergency situation should be considered meticulously. (Wessberg et al. 2000)

When following ISO 14 001 standardization system, which is part of the EMAS system, the organization has to create and maintain procedures for identifying and managing the possible accidents and emergency situations. The organization also has to prevent and mitigate the possible negative environmental impacts caused by their operations. Organisations have to review and update, when necessary, the procedures and strategies of emergency situations, especially after the accidents. The incidental emissions to air, water and soil, and the various impacts to nature and ecology by the incidental emissions should be analysed in terms of the practical operations of the company. The damage that is or can be caused by unusual operating conditions or accidents and possible emergency situations has to be taken into account in procedures. (Wessberg et al. 2000)

3.3 Environmental risk assessment

Environmental risk is a risk that may cause environmental damage or harm. In terms of environmental risk assessment, an environmental risk is a risk caused to the nature by a business operation. The environment consists both of nature and cultural environment. Environmental risk can be risk towards health, ecology or welfare. All these three risk perspectives include also the economical consequence, and thus environmental risk can correspondingly be seen as economical risk. The basic principle of the risk management is that there is no so called zero-risk, but the operation has always a risk. Thus, some risk has to always be tolerated, though in principle no risk of incidental emissions is acceptable. (Wessberg et al. 2000.)

Environmental risk assessment is a systematic tool of examining the environmental problems and risks resulting from technology that threaten ecosystem, animals and people. It is used in analysing different kinds of problems by their nature. In site-specific risk assessment, the focus is on the range of risks posed by a particular installation. The basic division of environmental risk assessment is the division to hazard-based and risk-based approaches. The first-mentioned approach concentrates on all the potential hazards that may or may not arise. In contrast, the risk-based approach focuses on the actual risks imposed by an environmental issue. Environmental risk assessment can be done for a single action or product, for industrial plant or even for a city. Environmental risk can occur during any stage of a product's or service's lifecycle: manufacturing, distribution, in use or disposal process. (Fairman et al. 1998)

The basic pattern of environmental risk analysis begins with the identification of the environmental impacts, containing the risks and probabilities. Then the consequences of the identified environmental impacts are assessed, and the significance is evaluated. The third step is to find the arrangements to develop the state of affairs, and the implementation of proposals for improvement. These steps can be found both from EMAS-system and ISO 14 001 series standards, as well as from many other environmental management tool systems, though, the division and emphasis can be somewhat different. There are also specialised methods for concentrating on some specific field of action, for example

the safety of the organisation. The proposals to improve the operation are usually easy and cheap to implement, such as some minor technical change or alteration in code of conduct. The most effective way is to look for solutions that may solve several risks at the same time, and not all the risks are solved separately. One of the most effective improvement methods is the training of the management and personnel. (Wessberg et al. 2000.)

Environmental risk analysis helps in identifying and preventing the possible incidental emissions and their harmful impacts to nature. To be able to prevent the possible emissions, the vulnerabilities of the system and the processes have to be recognised. After identifying the possibilities, the evaluation of the risks caused by them can be done. The factors to be concentrated on in risk assessment are naturally the possible previous environmental hazards caused by the company but also its current processes and storages, tracking and alarm systems, environmental conditions of the surroundings and the possibly existing plans for states of emergency (Lumijärvi & Kela 2000). The environmental risks can be classified according to the probability to expose the receptors and consequences when realised, see Table 1 below. These together determine the level of the risk and helps in prioritisation of the risks.

Table 1 Environmental risk assessment (RSC 2008, Wessberg et al. 2000)

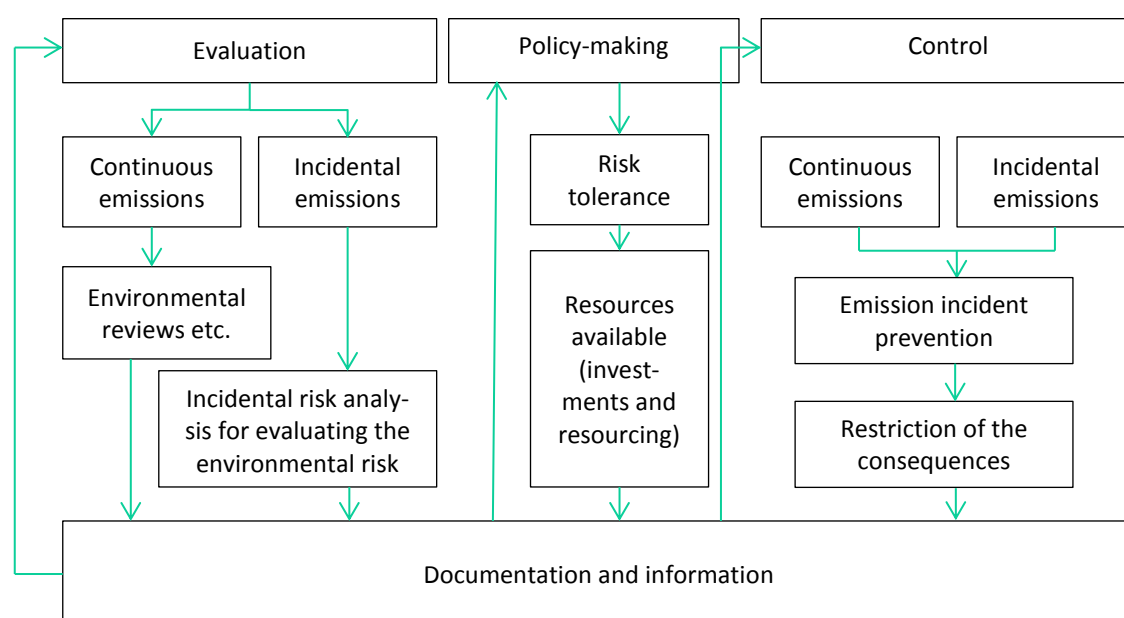
Probability of receptors being exposed ↑	High	Medium risk	Medium risk	High risk	High risk
	Medium	Low risk	Medium risk	Medium risk	High risk
	Low	Low risk	Low risk	Medium risk	Medium risk
	Very low	Very low risk	Low risk	Low risk	Medium risk
		Very low	Low	Medium	High
		Consequences of hazard being realised →			

Planning target (indicated by a red arrow pointing to the 'Medium risk' cell in the 'Low' probability row)

After identifying the risks, the probabilities and consequences of the hazards are evaluated, on a scale from very low to high. The risks are placed in the table according to these evaluations, and thus the nature of the risks is seen. The evaluation is dependent on the targets and limit values of the emissions set to the company, and thus the risks analyses are not necessarily comparable. The nature of the risk also affects the classification. When analysing the industrial processes in operation, usually only one or two risks are considered high risks, if any. Medium risks are identified more, however, and the majority of the risks are usually low or very low risks. (Wessberg et al. 2000.) In this study, the risk analysis tools base on the environmental risk analysis method SARA developed by VTT Technical Research Centre of Finland (see Wessberg et al. 2000) and the RSC (2008) note on environmental risk assessment.

There are several approaches to environmental risk management. When eliminating the risk, the use and marketing of a substance is completely banned. However, the banned product is usually replaced by another and thus one risk is substituted by some other. The risk can be transferred to other bodies or retained by a company or government. In most policy decisions and environmental management situations, the chosen method is risk

reduction, which in practice is usually an investment for new, more efficient technology or operation mode. (Fairman et al. 1998.) Wessberg et al. (2000) suggests somewhat different environmental risk management strategies, being avoidance, reduction, relocation or keeping the risk. Risks can be avoided by identifying the hazards and avoiding the things that cause risks. Risks can be reduced in many ways, for example by educating the employees and investing in safety. Similarly as in the previous view, a company can share the risk by transferring it to be some other party's responsibility, the other party usually being a chemical supplier or an insurance company. However, in some cases it is reasonable to keep the risk and be liable for it by the company itself. Risk management can be seen either as a prevention of hazards or restriction of the consequences, the first of which is often seen as primary risk management. Restriction of the consequences usually means the prevention of the distribution of an emission or other hazard. The progression of the incidental emissions can be controlled by e.g. protection systems, evacuation of the people and pets or replacing the contaminated water intake point with another. The field of environmental risk management is shown in Picture 3.



Picture 3 The field of environmental risk management (Wessberg et al. 2000)

The common problems of all the environmental risk analysis methods relate to uncertainties and difficulty in collecting the suitable data. The identification of possible emissions cannot be all-encompassing, and the defining of the possible consequences is always inexact. Also, a fundamental problem in environmental risk assessment is the evaluation of the harm caused by a new substance or action. It can be assumed that all the substances or agents are harmless, until proved by science to have harmful effects. On the other hand, all the agents can be considered harmful until proved to be safe. (Fairman et al. 1998.)

The precautionary principle is central in the EU's approach to environmental issues and will be used in this evaluation as well. Another problem of the environmental risk assessment is the problematic nature of the risk prioritization of different types of risks. Thus the division of the efforts to be used for prevention of the risk is challenging. One difficulty lies in finding suitable methods for prevention of harmful environmental impacts and

for limiting the occurred emissions. Nevertheless, despite the uncertainties, environmental risk analysis gives certain benefits for the company. The survey of incidental emission possibilities responds to the environmental protection needs of a company and gives an image of an environmentally responsible company. It helps in ensuring the continuity of operation in case of accident or other disturbances. Thus, preparing for the environmental hazards is chiefly securing the economic activity of the company. When implemented well, environmental risk analysis is an investment, which ensures the continuity, and not an additional cost factor. (Wessberg et al. 2000.)

4 TORREFIED WOOD PELLETS

Torrefaction is a heat-treatment process that improves the fuel properties of biomass. The process is executed in the absence of oxygen, in a temperature of 200 - 300 °C. During the process, 30 % of the dry mass converts to torrefaction gases, but the end product contains 90 % of the initial energy content of the biomass. The roots of the torrefaction process are both in pyrolysis and coffee bean roasting. The torrefaction process is also called mild or slow pyrolysis, and the connection to the pyrolysis process is clear, though the conditions under which the processes are carried out are different. (Bergman et al. 2005.) Connections to coffee bean roasting are also apparent, though it is carried out in a lower temperature and in the presence of oxygen. Though the process has been used in the coffee industry for centuries, in terms of bioenergy it is a relatively new process. The first pilot plant of torrefaction was built in 1980's, but for other purposes than bioenergy production (Bergman & Kiel 2005). That plant was later demolished, but the interest in bioenergy applications of torrefaction process remained. A lot of research and technology development has been done especially in northern Europe and North America, but only a couple of commercial scale torrefaction plants are yet in operation (Schorr et al. 2012).



Picture 4 Untreated wood chips, torrefied chips and torrefied wood pellets (Volama 2011)

In Picture 4 above, there is the same wood biomass shown in its several stages. The ordinary wood chips (background) are first torrefied (on the centre, left hand side) and then pelletized (on the centre, right hand side). These stages and the properties of the fuel are discussed in more detail in the following chapters.

4.1 Raw material

In general, torrefaction technology can be applied to various kinds of biomasses. This study concentrates on forest bio-energy and more precisely on wood-based fuels. Logging residues, small-diameter wood and stumps are side products of forest industry, which are not exploited in their industrial processes. These all can be chipped and thus utilized in biofuel production, e.g. in torrefied wood pellet production. Naturally log wood could also be used in the torrefaction process, but when thinking about the sustainability of the production chain that is not reasonable. (Vanninen 2009.)

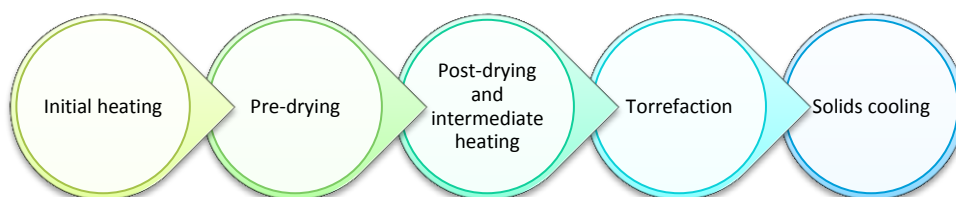
About 50 % of all the biomass is lignocellulose, which is composed of cellulose, hemicellulose and lignin. Biomass can be processed in various ways in order to produce e.g. biodegradable materials, chemicals, fuels and energy. Lignocellulose is the main component of wood. In Finland, lignocellulose materials that could be utilised in industrial production are primarily wood, peat, bark, wood residue, straw, reed canary grass and some wastes. At the moment, the lignocellulose materials are used mainly in energy production. The most common species of hardwood in Finland are silver birch and downy birch, and the main softwood species are pine and spruce. The composition of the wood varies among species, growth conditions and parts of the tree. (Vanninen 2009.) Pine, spruce and birch contain cellulose 40 - 50 % of the dry weight. Coniferous trees, i.e. softwood, contain less (25 - 28 %) hemicellulose than deciduous trees, i.e. hardwood (37 - 40 %), but on the other hand, the lignin content is higher in coniferous wood (24 - 33 %) than in deciduous (16 - 25 %). Lignin ties the wood fibre together and gives the mechanical strength for the wood. Lignin contains much carbon and hydrogen, ergo, heat productive elements. In addition, wood contains also extract compounds, such as terpenes, lipids and phenols, representing the 5 % share of the dry weight of wood, but in bark the content can be even 30 - 40 %. Wood contains much volatile compounds, 80 - 90 %, which makes it burn with long flame and require large combustion chamber. (Alakangas 2000.)

On an elementary level, wood consists mainly of carbon and oxygen, which together represent approximately 90 % of the dry mass. About 6 % of the mass is hydrogen, and the remaining 4 % consists of nitrogen, potassium, calcium, phosphorus, magnesium, sulphur and iron. (Vasara et al. 2001.) Nitrogen content is clearly under 0,2 % in all tree species, and sulphur content is less than 0,05 %. Different tree species differ from each other only moderately in their elemental composition. (Alakangas 2000.) Bark and needles or leaves consist of the same elements as wood, but the concentrations vary (Vanninen 2009). Wood may also contain some heavy metals, which are mainly concentrated in the bark (Vasara et al. 2001). The ash content of bare wood is usually less than 0,5 %, and for bark of coniferous wood it is less than 2 %. The ash content of wood in general is lower than for many other solid fuels, which makes the ash treatment cheaper and easier. (Alakangas 2000.)

Logging residue contains all the wood-based biomass that is left unused in forest after round wood harvesting and other forestry activities. Forest residues represent up to 40 % of the biomass of harvested wood, and thus small-diameter wood, branches, treetops, roots and stumps could be exploited in energy production efficiently. (Vanninen 2009.) The amount of the logging residue alters in different forestry operations. After the first thinning, the residue is mainly small-diameter wood and the total amount remains small. After partial logging or complete clear cut the gained logging residue contains branches, needles and partly decayed logs. The amount of logging residue depends on the tree species, the amount of trees, the robustness and the number of branches and decayed parts. In spruce forest the amount of logging residue is twice the number of the residue in pine or birch forests. Larger amounts of logging residue make its utilisation more efficient. Logging residue can be harvested right after the logging, when it is fresh, or left to the site to dry up so that the leaves and needles fall and deliver the nutrients back to the soil. If the residue is left on site for a couple of months in summer time, the humidity decreases to 20 - 30 %. Thus, the solid wood content increases, but the amount of collectable logging residue diminishes even 20 - 30 % due to the fall of the needles. Thus the amount of captured forest residue is approximately 55 % smaller than when it is fresh. (Alakangas 2000.) According to forestry guidelines, forest residue utilisation is sustainable, when one third of the residue and some stumps are left in logging site. The chemical features of stumps and roots are close to the ones of stem wood. The features of branches, needles and leaves vary more, and in general it could be said that the logging residue contains more inorganic elements than the stem wood. (Vanninen 2009.)

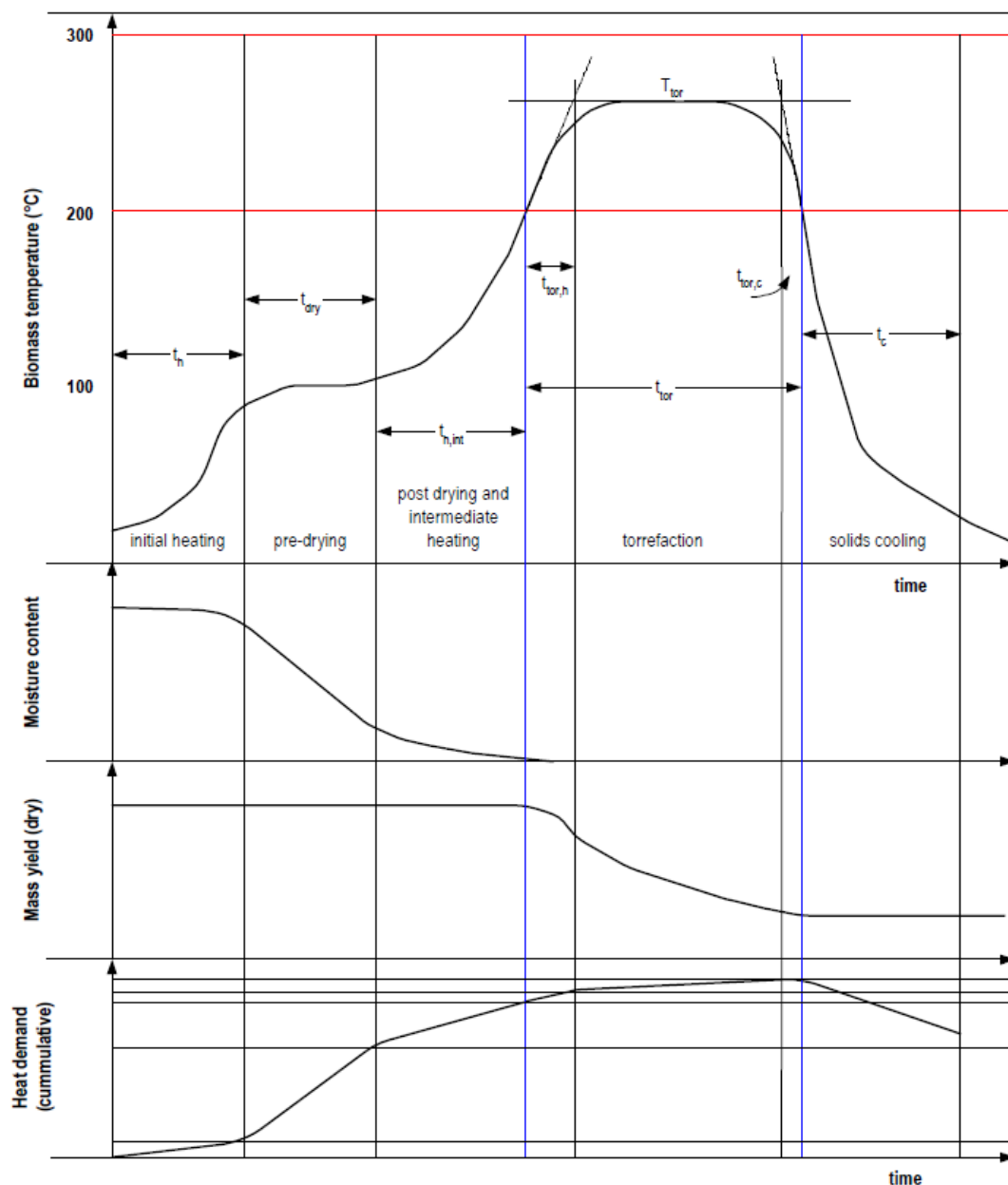
4.2 The torrefaction process

Torrefaction is a thermochemical process in which the biomass is heated up to 200 - 300 °C. Before the torrefaction, biomass has to be dried so that the moisture content is 20 % at most. The drying process can exploit the synergy effect of industrial processes nearby if there is industrial waste heat available, but the process gas of torrefaction can also be burned to produce heat. The torrefaction process is carried out in the absence of oxygen, under atmospheric conditions. Typically, the process is characterised by low particle heating rate (< 50 °C/min) and long residence time (~ 1 hour). The biomass gets roasted during the process and gives off various volatile compounds. The final product is the remaining solid material, which is called either torrefied biomass or (bio-) char. Bergman et al. (2005) divided the process into five sections: initial heating, pre drying, post-drying and intermediate heating, torrefaction and solids cooling. The torrefaction process is shown in Picture 5. The stages of the process are discussed more precisely in the following chapters.



Picture 5 The torrefaction process

During the first stage the biomass is heated up. At this point the temperature rises, but no water evaporates yet. The stage ends when the temperature approaches 100 °C and water starts to escape. The second phase is pre-drying, when the temperature keeps constant, but the biomass gets dried due to water evaporation. When the biomass gets dry enough, so that temperature starts to rise again, the stage ends. During the phase of post-drying and intermediate heating, the temperature rises up to 200 °C. At this point the remaining water evaporates and therefore the moisture content gets close to zero. During the phase of torrefaction, the temperature rises up to 200 °C. At this point the remaining water evaporates and therefore the moisture content gets close to zero. (Bergman et al. 2005.) The density of torrefied material is approximately 10 - 20 % lower than that of dried raw material. At the end, the mass is cooled down. The torrefied material is partly dust-type and contains fine material, because of which the material is pelletized in order to enhance the handling properties. Biomass is dried completely in the torrefaction process, and afterwards the moisture uptake is very limited, approximately 1 - 6 % depending on the level of torrefaction and post-processing of torrefied biomass. (Bergman 2005.) The torrefaction process is described more precisely in Picture 6.



Picture 6 Stages of torrefaction (Bergman et al. 2005)

The process time is sum of the time of initial heating (t_h), drying time (t_{dry}), intermediate heating time ($t_{h, int}$), reaction time at desired torrefaction temperature (t_{tor}) and cooling time (t_c) to ambient temperature. Reaction time of torrefaction consists of time of heating from 200 °C to desired temperature (T_{tor}), the desired duration time in that temperature, and cooling time from the desired T_{tor} to 200 °C. At this point, the torrefaction process is considered to end and the final cooling phase starts. As it can be seen, the moisture content gets to zero during the first three stages, and after that the mass yield is getting lower, as the volatile compounds escape and the torrefaction gases are produced. The gas contains approximately 50 % of water, and 10 % of CO₂, thus the incombustible material content is about 60 %. The exact amount depends, however, on the humidity of the raw material and process properties. (Bergman et al. 2005.)

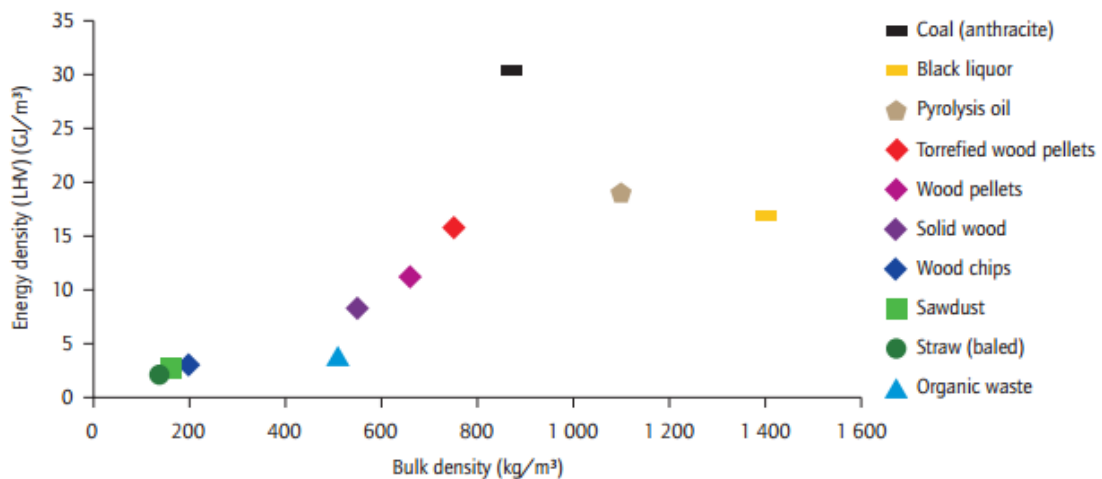
The end product is fuel, which is easy to handle and transport, and which has high energy content. In addition the physical features of the biomass change: initially hard and fibrous material becomes brittle and easily breakable. Thus the energy needed for the pelletizing compared to traditional pellets is reduced by 70 - 90 %. Another benefit is that the steam treatment needed in traditional pellet production is not needed in pelletizing of torrefied biomass. (Pöyry Management Consulting 2011.)

In addition to the torrefied wood, various reaction products are formed in the torrefaction process. The process conditions affect the yield of the side products, as well as the quality of the end product. Bergman et al. (2005) classified the side products by their state in room temperature. The solid side products are sugars, newly formed polymeric structures including some amount of aromatic compounds, carbon-rich char structures and ash. Many of the liquid compounds in room temperature are actually in gaseous state in the torrefaction process, and the classification of gaseous products includes only permanent gases, such as carbon monoxide and carbon dioxide, methane and hydrogen gas, but also some aromatic components such as toluene and benzene. The condensate liquid products are water, organics and lipids. The torrefaction gases can be burned and the produced heat be returned to the torrefaction process, which increases the energy efficiency of the process to more than 90 % (Pöyry Management Consulting 2011).

4.3 Fuel properties

Torrefied wood material has high net calorific value of 20 - 22 MJ /kg and high energy density of $>14 \text{ GJ/ m}^3$, while traditional wood pellets have the energy density of only 10 - 12 GJ /m³. Thus, torrefied wood pellets have more than 20 % higher energy content per volume than traditional wood pellets. Due to the lower water content, the transportation and handling costs of torrefied pellets are lower than wood pellets. Torrefied pellets are hydrophobic, which is ideal for handling and long-term storage. The chemical and physical features of torrefied material are close to properties of coal. Thus, the torrefied pellets can be combusted or co-combusted in conventional (coal-fired) power plants and consequently, the extra investments on new incineration technology can be avoided. The torrefied wood fuel has low sulphur and ash content compared to coal, and better combustion behaviour compared to non-torrefied biomass. Capacity constraints of power plant are significantly reduced in comparison to un-torrefied wood pellets. Torrefied material has also improved grind properties compared to traditional wood pellets. (Wolfgang 2012.)

Biomass pre-treatment increases its fuel properties. Compared to solid wood, wood pellets have better energy and bulk densities. However, when wood chips are first torrefied before pelletizing, the fuel properties get even better. In Picture 7 below, the different biomasses are allocated based on their energy density and bulk density. According to fuel properties, it can be said that pelletizing, torrefaction and pyrolysis are the key pre-treatment technologies for wood biomass. (Eisentraut 2012)



Picture 7 Comparison of bulk density and energy density of different biomass feedstock (IEA 2012)

Since torrefaction is not done on a commercial scale yet, the price level of torrefied wood pellet is not certain. Among the increase of the usage of wood-based bioenergy, its price volatility is also likely to increase. Price indices and other price prediction systems are commonly used in the traditional energy sector and are likely to spread also into wood-based bioenergy products as their volume increases. (Teräs 2012.) The production and distribution costs of torrefied wood pellets are divided into three sections: raw material (63 %), torrefaction and pelletizing (27 %) and storing and transportation to power plant (10 %). It is estimated that the production costs of the torrefaction and pelletizing are approximately 50 €/t. In addition to this, the costs of raw material purchase and logistic are added. (Pöyry Management Consulting 2011.) According to market research of torrefied wood pellets, in which the potential markets of the pellets were discovered, there are European-wide markets for torrefied pellets. When pursuing the renewable energy targets, there will be national markets also in Finland. (Karhunen et al. 2011.)

As described previously, wood chips can be processed into traditional wood pellets, or they can be first torrefied and then pelletized. The effect of the refinement on the fuel properties can be seen in Table 2, where the wood chips, traditional white pellets and bio-coal, i.e. torrefied material, are compared. (Pöyry Management Consulting 2011.)

Table 2 The comparison of the features of wood chips in its different refinement levels (Pöyry Management Consulting 2011)

	Wood chips	Pellets	Bio-coal (torrefied material)
Moisture content	35 - 45 %	8 - 10 %	1 - 5 %
Calorific value (GJ/odt, net)	17,7	17,7	20 - 23
Bulk density (kg/m ³)	475	500 - 600	750 - 850
Energy density (GJ/m ³)	5	8 - 10	15 - 18

Refinement of the wood chips into pellets or bio-coal remarkably increases the bulk and energy density, which decreases the transportation and handling costs. Torrefaction gives additional value to wood biomass refinement, since it enables the utilisation of biomass in traditional power plants in a new level.

4.4 Use of torrefied wood pellets

The torrefied material is developed especially for co-firing purposes in existing coal-fired power plants. The possibility to utilise biomass in traditional power plants is attractive because of the existing power plant infrastructure and market volume, comparable fuel properties and expected cost savings. (Schaubach 2012.) The similar handling and storage properties of torrefied biomass and coal can reduce the investment costs of transiting an existing coal-fired power plant into a co-firing plant. Replacing part of coal by torrefied biomass reduces also CO₂-emissions remarkably, approximately by 0,42 kg/ kWh. Use of torrefied wood pellets will support achieving the EU targets of 20 % share of renewable energy sources. At the moment, approximately 4,5 million tons of biomass is already co-fired in the EU, but it could be done more efficiently by using the torrefaction process. (Wolfgang 2012.)

Vattenfall has a project for increasing the level of co-firing in the hard coal plants and thus reducing fossil CO₂ emissions by 8 - 10 Mt /a. In this Test and Verification Programme, the whole power plant process from ship unloading to chimney was investigated. In practise, the processes of logistics and storage, milling, boiler and combustion, and flue gas treatment and by-products were analysed. The tests were done in Germany, at Reuter West CHP plant (CHP = Combined Heat and Power). Unloading and transfer to conveyor tests resulted that the tested pellets can be unloaded with existing system of a coal-fired power plant, given small adaptations in dust suppression system and in the unloading system grabs. Though the total dust fall of torrefied pellets was at some points higher than in coal handling, the tests showed that conveying is possible with coal conveyors. Storage tests were done in hard coal yard, in the open air. The test resulted that storing can be done in open air, but ground insulation has to be installed in order to prevent the leaching water access into ground. Addition of pre-treated biomass had no impact on boiler operation, by-products or emissions according to the tests at biomass share of 20 %. (Nordlander 2012.)

During the test campaign, the Reuter West CHP plant operated at 20 - 50 ma% co-firing rates for 9 days without any technical modifications. Such co-firing rates could not be achieved with conventional biomass without significant investments. The results show low cost feasibility of co-firing refined wood pellets. According to the tests, CHP co-firing of refined wood pellets is a superior energy production method compared to e.g. a Bio-CHP plant or an offshore wind park. The capacity of a wind park can be slightly higher than that of co-firing, but on the other hand, the amount of produced energy is higher in co-firing. The investment costs are the lowest in co-firing, Bio-CHP being somewhat more expensive and the costs of a wind park being tenfold. CO₂ reduction, assuming the CO₂ efficiency being 90 % in co-firing, is the highest in co-firing of refined wood biomass. (Nordlander 2012.)

The clear benefit of the usage of torrefied wood pellets is the reduction of total CO₂ and SO_x emissions when comparing the torrefied material co-firing to sole coal utilisation. Thus, the net profit of CO₂ certificates and incentives is achieved. Also, the fuel basis is made more diverse, and the achievement of green energy production goals is approached by development of renewable energy sources. (Wolfgang 2012.) A social benefit is the creation of new, permanent jobs for whole production chain, from forest to power plant and transportation (Weick 2012).

4.5 Environmental impacts of the production: case Torr-Coal

A Dutch company called Torr-Coal has a torrefaction plant in operation, with output of 2 t /h of torrefied material. In 2013, the output is about to be doubled, and the pelletizing unit is under planning. The raw material of the plant is wood chips, being mixture of deciduous and coniferous trees obtained both from forest and park. The torrefaction process is run at temperature of 290 °C in an indirectly heated rotary furnace. (Sluijsmans 2012.)

The environmental impacts of the plant are almost exclusively emissions to air. The gas produced in wood biomass torrefaction is filtered for dust removal, and then burned in an incinerator. After incineration, the flue gases are at temperature of 1 000 °C, and the heat is used to keep the temperature ideal in the torrefaction rotary furnace. The flue gases are emitted into air at a temperature of about 200 °C. The heat is also used for drying the untreated wood chips to a water content of < 10 % in a belt dryer. The air used for drying and the evaporated water are released into the air as such, the dust content being approximately < 20 mg /Nm³. The concentrations of the substances in the flue gas are remarkably low, and thus the load to the environment is rather low. (Sluijsmans 2012.) The measurement data of the flue gas composition is shown in Table 3.

Table 3 The emissions of Torr-Coal torrefaction plant (Sluijsmans 2012)

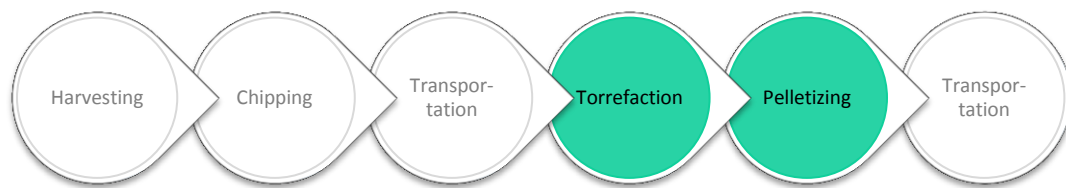
	Measurement 1: 19 th May 2011		Measurement 2: 4 th November 2011	
	11 % O ₂ [mg /Nm ³ dry]	kg /h	11 % O ₂ [mg /Nm ³ dry]	kg /h
Dust	1,2	0,01	2,6	0,02
CO	6,1	0,03	15	0,13
NO_x	255	1,44	156	1,35
SO₂	56	0,32	24	0,21
Dioxin / furan	0,011*	--	--	--
TOC	3	0,02	3	0,03
HF	0,5	0,003	0,2	0,001
HCl	14,7	0,08	17,4	0,15

*) ng TEQ/Nm³ dry

The measurement result of the emissions from Torr-Coal torrefaction plant meet the stringent Belgian statutory emission standard. However, there are some technical deviations in the torrefaction processes of Torr-Coal and the torrefaction equipment supplier of Pursiala pilot plant, Jartek Ltd, and thus the emissions cannot be assumed to be similar. One of the key differences is the way by which the anoxic conditions are maintained. In Torr-Coal's process, nitrogen is used as an inert gas, but Jartek has planned to use water vapour for replacing oxygen. Therefore the NO_x emissions should be remarkably lower in Jartek's process. The sulphur content of wood is very low, and thus, when torrefying only wood material, the SO₂ emissions should be minimal. The HCl content of the Torr-Coal plant measurements seems very high and can probably be explained by the high amount of needles and park biomass in the raw material. It must be noted that at the moment, Torr-Coal's process does not include pelletizing, and thus its emissions (mainly dusting) are not taken into account here.

5 THE PRODUCTION CHAIN OF TORREFIED MATERIAL PRODUCTION

The production chain of the torrefied wood pellets, in respect of this study, starts from forest and ends in transportation of ready-made torrefied fuel to the end user, see Picture 8. However, some steps are handled only on a general level, and their environmental impacts are not analysed specifically. In environmental impact assessment, the discovered chain should cover the whole process, but in order to provide valuable and accurate enough analysis, the operations analysed more in detail are the processes inside the torrefaction plant, i.e. torrefaction and pelletizing. Both the Rislog and its pilot plant projects are still at the initial stage, and the raw material supply is not specified yet. Thus, the impacts of the raw material collection can be handled only on a general level. Similarly, since there are not commercial markets and/or large-scale use of the torrefied wood pellets yet, or specific end-user of the product, the impacts of the co-firing of torrefied material are rather hard to estimate. Therefore, the impacts of the transportation to the power plant cannot be estimated either, because the distance and used transportation means are unknown. Something general can be said about the transportation means available in Ristiina, so that stage is also discussed in brief.



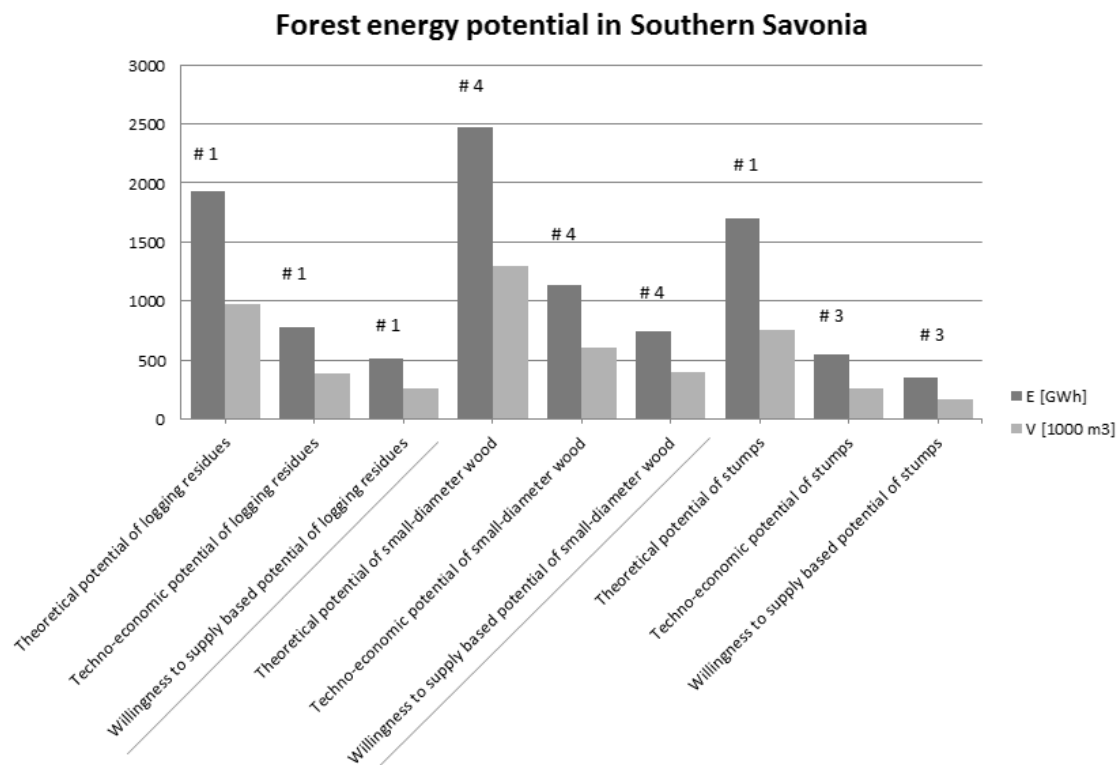
Picture 8 The production chain of torrefied wood pellets

In addition to the stages mentioned in Picture 8 above, there can be several storage phases in between the stages. The points and ways of storage depend on the process features and the operators. The storages outside the torrefaction plant are not considered in this analysis, but some general guidelines are mentioned. In the following chapters, first to be discussed is the supply of raw material suitable for torrefaction process in Southern Savonia region. Then the environmental impacts of the first three steps of the production chain are analysed. These sections are common for both of the pilot and Rislog plants, though on different scales. The plants and their environmental impacts are handled separately in their own chapters. Due to the different locations and scales of the operation, the final transportation is also covered briefly in these sections.

6 ENERGY WOOD POTENTIAL IN SOUTHERN SAVONIA REGION

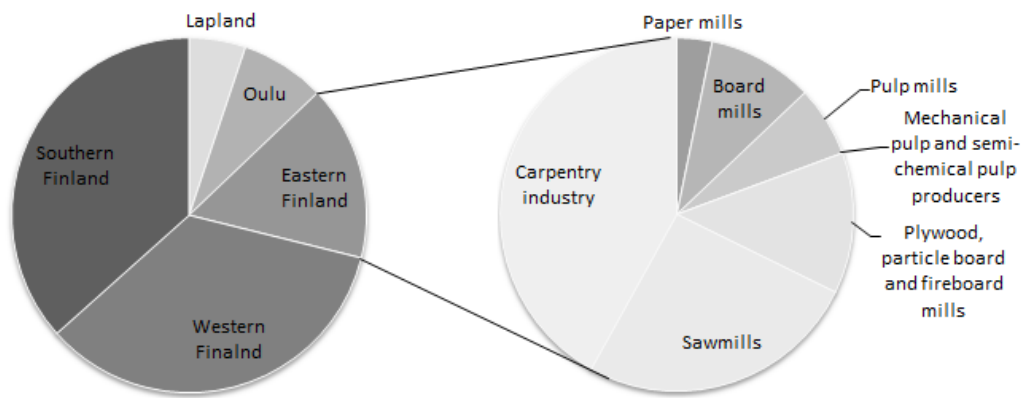
In Finland, the forested area has remained almost constant since 1930s. However, the forest growth is almost doubled since 1970s, so the forest biomass has increased significantly during the decades. (Kauppi 2012.) In the Southern Savonia region, there is the largest biomass potential available in Finland when looking at the technical and economical cutting potential, but considering also the willingness of the forest owners to sell the energy wood. The energy wood potentials can be calculated either in theoretical, techno-economic or willingness to supply basis. The theoretical view considers all the biomass and thus represents all the biomass available. The techno-economical approach takes into account only the biomass that is both technologically available and economically reasonable to collect. However, getting wood into market depends ultimately on the forest owner, and thus it is worthwhile to consider their willingness to supply the wood biomass. Naturally, this willingness to supply based potential is the smallest of these potentials, but easiest to increase. These should not be considered as separate potentials but different approaches to the same potential. The total theoretical forest energy potential in Finland is 3,0 hm³, total techno-economic forest energy potential is 1,3 hm³ and total willingness to supply based potential of forest energy is 0,3 hm³. (Maidell et al. 2008, 26.) Increasing the use of the forest chips to the level of its techno-economical potential, i.e. five-fold increase in current usage, would cover only 6 % of the total energy consumption of Finland (Kuusinen & Ilvesniemi 2008). Therefore, it is not the all-embracing solution for meeting the GHG reduction targets, and other renewable energy sources should be developed as well.

The total potential of forest energy can be classified by its sources. In Picture 9 below, the theoretical, techno-economic and willingness to supply based potentials are shown for logging residues, small-diameter wood and stumps. The potentials of logging residues in Southern Savonia are the largest in Finland. In case of small-diameter wood, Southern Savonia has the fourth greatest potential in the country. When talking about stumps, the theoretical potential is the largest in Finland, but techno-economic and willingness to supply based potentials are only third largest in the country. The potentials are shown both in energy content (GWh) and volume (1 000 m³). (Maidell et al. 2008.) In practise, however, the recoverability is limited by harvest volume fluctuations of the wood industry and the forest owners' willingness to sell wood biomass and stumps, but also by the harvesting support system and financing conditions.



Picture 9 Forest energy potential in Southern Savonia (based on Maidell et al. 2008)

Despite the large potential of wood, the refinement level in the Southern Savonia region is low, and a large number of the raw material is transported to be refined outside the region. Approximately 16 % of all forest industry plants in Finland are located in the Eastern Finland province. The province consists of three regions, one of them being Southern Savonia with 5 % share of the total. The forest industry in the Southern Savonia region is mainly plywood, particle board and fireboard production, sawmills and carpentry industry. (Metsäteollisuus ry 2012.) The shares of the provinces and the types of wood industry in Eastern Finland are shown in Picture 10. There is an initiative to increase the refinement level in the region, which sets the need for the processing plants.



Picture 10 Forest industry in Eastern Finland (based on Metsäteollisuus ry 2012)

Refinement of wood biomass in Southern Savonia would be valuable for the region because of new jobs and material of higher refinement level to be sold outside the area. In terms of the regional economy, forest energy production can give regional benefits on those operational environments where there is no chemical forest industry, as in Southern Savonia. In addition to sufficient raw material potential, the sourcing logistic requires adequate machinery and skilled and motivated workforces. Thus, forest chip production means direct, local employment effects in the region. It is estimated that the demand of forestry machines will double by 2025, and 8 000 employees are needed in addition to the current workforce in whole forest energy production chain in Finland. (Lauhanen & Laurila 2008).

Considering the other sectors of society, one employee of the forest machinery producer employs two others, and one job in forest energy production means 1,4 - 1,5 jobs in other sectors. The net effect of logging residue chip production is 18 - 24 €/m³ and of log wood chip production 29 - 38 €/m³, depending on the chip type and production technology. In combined procurement of log wood and forest energy on a large-scale, the share of the work done in forest stays in local economy, but the benefits of the refinement go to industrial localities and domiciles of the companies. Thus production of biofuels in a local refinement plant will bring additional value for a region. (Lauhanen & Laurila 2008).

It is possible to increase the level of the utilisation of wood in energy production sustainably. As long as the growth of the forests is greater than their reduction, the forest reservoirs grow. In 2006, the net growth was approximately 31,6 million m³. Despite the large biomass potential, especially spruce logs and pulpwood were harvested more than it is sustainable during the last decade. Unsustainable loggings may occur, especially locally, since the loggings are not always distributed equally. However, the thinning potentials will grow in future in the whole country. The growth of the utilisation level of the forest chips has been fast and its use for energy purposes has almost quadrupled during the 21st century. This was due to several huge plant investments in the beginning of the century and at the moment, the 30 largest energy plants use 75 % of all forest chips. However, this is only approximately one fifth of the total harvesting potential of 16 million solid m³. The utilisation level of the canopy biomass is the highest, being approximately 30 %, but only 10 % of the small diameter wood potential is exploited in the energy production. The largest untapped potentials are in Eastern and Northern Finland. (Laitila et al. 2008.)

In 2006, the target was set for forest chips utilisation to be at least 8 million m³ by 2015, to be achieved, however, in a way that will not harm the heterogeneity of nature or nutrient balance of forests. The effects of the growth in energy wood harvesting and the harvesting methods are considered in legislation and counselling in order to ensure the prevention of harmful effects. The remarkable environmental effects would be for instance the increase of endangeredness of endangered species, the devolution or endangeredness of other species, harmful impacts on long-term productivity of forest soils or remarkable harmful effects on other products of the ecosystem (e.g. mushroom yield, water quality). (Siitonen 2008.)

7 MATERIALS AND METHODS

This study is done on the basis of literature, seminar presentations and interviews. In addition to a literature review, the professionals of torrefaction technology and energy production were interviewed. Jussi Karppanen from Etelä-Savon Energia Ltd. was interviewed on the raw material supply of the Pursiala power plant. The equipment suppliers of the pilot plant, Jartek Ltd. and Promicco Ltd., provided information of their processes and the expected environmental impacts. Neither of the torrefaction plants whose environmental impacts are assessed in this report exists at the time of writing, so all the process structures and environmental impacts are rather estimations. Nevertheless, the estimations should be as accurate as possible, and deviations from reality should be moderate.

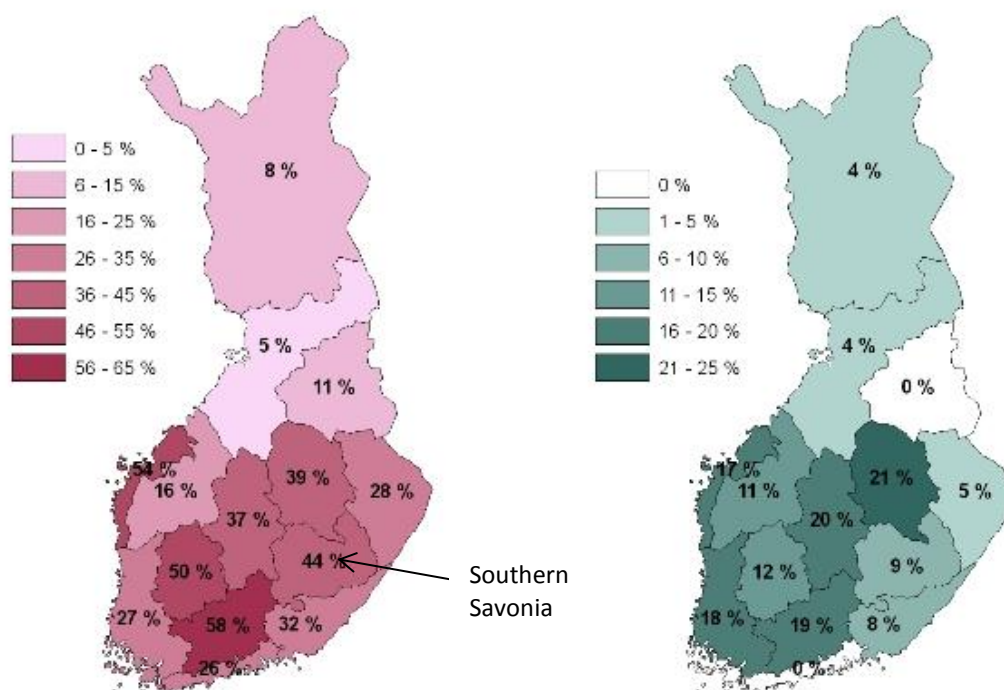
Several other companies developing the torrefaction technology were contacted in order to ask about the measured emissions of the existing plants. Jo Sluijsmans from Torr-Coal Groep was of great help by offering their measurement data for my use. The company has a torrefaction unit of 2 t/h output of torrefied material in Netherlands. The technology and the environmental impacts of the plant are presented later on as a case of a functioning torrefaction plant. Because many of the torrefaction-oriented organizations are still developing their processes, this kind of information of the environmental impacts is mainly confidential and only some general limit levels could be shared. Another problem of the information-gathering of measured environmental impacts of torrefaction process was that many of the pilot plants do not operate continuously, and thus, only some unsystematic measurements have been done. I want to express my gratitude also to Jari Hiltunen from Andritz Ltd. for information about their pilot plants in Stenderup, Denmark and Frohnleiten, Austria.

8 RAW MATERIAL COLLECTION AND ITS ENVIRONMENTAL IMPACTS

8.1 Harvesting of wood for energy utilisation

In terms of environmental impacts, the decisive factor is how intensively and widely energy wood is harvested. The raw material of forest chips are branches, canopies and stumps. Above-ground biomass is collected both from thinning and final felling sites, but

the stump removal is limited to final felling sites. Due to the differences in the intensity of the collection, in some areas the energy wood collection will be very intensive in the future. See the levels of year 2010 in Picture 11. (Kuusinen & Ilvesniemi 2008.)



Picture 11 Canopy biomass harvesting sites (left) and stump lifting sites (right) in 2010, % of total area (Tapio 2011)

Wood for energy utilisation is collected both from final felling sites and forest management, i.e. thinning sites of young forests. At the moment, canopy biomass and stumps collected during the final felling represent 70 - 80 % of total forest chips utilised in energy production and small diameter wood the remaining 20 - 30 % of forest chip volume. (Saksa 2008.) The harvesting costs of logging residue chips harvested from final felling site are the lowest, while the costs of small diameter wood chips' collection from thinning site are the highest. At the current energy price levels, harvesting of small diameter wood is possible only because of the support system, and thus the development of cost-effective harvesting methods plays a key role in improving the competitiveness of small diameter wood chips. (Saksa 2008).

The amount of treetop and stump biomass collected from final felling sites depends largely on the wood industry's raw material demand, i.e. the amount of loggings. In energy production purposes, mainly small diameter wood, logging residues, treetops and stumps are used, since log wood is more expensive and is purchased by traditional forest industries. The young forest management sites make an exception on this, because the amount of log-sized wood is relatively small, so that it is not reasonable to collect it separately. A typical energy wood harvesting site is unkempt, often deciduous tree dominated young growing forest where vast majority of collected wood is less than log wood scale. Emission trading system has improved the competitiveness of bioenergy compared to fossil fuels and increased the solvency of the energy producers. The use of wood-based energy

sources diminishes the need of import of foreign energy sources, in this case coal. (Saksa 2008).

The side products of forest industry processes are already utilized completely, so more wood for energy production purposes is got only from wood material that cannot be utilized in wood industry. The integrated harvesting of pulpwood and energy wood would diminish the total collection costs compared to separate harvesting. In this kind of case, the pulpwood and energy fraction would be separated only in the pulp mill's debarking drum. However, there are no established and cost-effective ways of integrated harvesting for first thinning sites yet, at least not so that they would be cost-effective also in long distance transportation as well. (Laitila et al. 2008.) On the other hand, there is a paradox in the increase of biomass utilization volume: it is done to prevent global environmental problem, but at the same time significant local environmental effects are caused. (Kuusinen & Ilvesniemi 2008.)

The effects are dealt more in detail in following chapters. However, energy wood harvesting is a relatively new operation, and no research data is available on all its impacts. Thus, many of the recommendations rely on the precautionary principle. Currently, energy wood harvesting is considered as forest management action, the purpose of which is to lead the forest in the best state possible for log wood production and the energy wood is more like a side product of this operation. Energy wood logging is the cheapest option, when the amount of the log wood to be cut is less than 20 m³ /ha, and correspondingly, the separation of the log wood from energy wood becomes efficient when the log wood content is more than 20 m³ /ha. Spruce trees of final felling age have approximately one fourth of the total biomass both in logging residues and stumps, being a bit less than a half of the total biomass altogether. For pines, the amount of logging residues above-ground is remarkably smaller. (Kareinen et al. 2008.)

8.1.1 Stumps

The stumps are collected almost exclusively from spruce forests, since its roots follow the surface and thus the wood material accrual per hectare is high. Pine, on the other hand, has deep pole root, which makes its raise difficult and inefficient. Laitila et al. (2008) estimated that 65 % of spruce final felling sites from which treetop biomass is collected are suitable for stump collection as well. The maximal collection potential of spruce stumps is 95 %, since some of them are left in the ground for ecological purposes. To achieve the goals of energy wood and stump harvesting, the energy wood could be collected from every third forest renewal sites. Since the harvesting concentrates mainly on spruce-dominated forests, the canopies would be harvested from two of the tree spruce renewal sites and stumps from every third sites. (Saksa 2008.) Lifting the stumps have a far greater effect on the ecosystem than logging residue collection. In order to prevent the possible harmful impacts in advance, the recommendations of energy wood harvesting should be followed. The recommendations require that 30 % of logging residue is left on site; old stumps and robust fresh stumps of different wood species are left without lifting totally ≥ 25 pcs /ha (in fine soils ≥ 50 pcs /ha). The existing deadwood should be preserved, and valuable forest nature sites are left outside harvesting. Stumps are not lifted from steep slopes, boulder fields or rock holes, wetlands, buffer zones of water bodies or close to spared trees or deadwood. Robust deadwood is more significant for many species than small diameter canopy or branch biomass, and thus its collection does not harm them.

Besides, because of the limitations of harvesting technology, approximately 30 % of the logging residues are left on site. (Siitonen 2008.)

However, lifting the stumps enables combining the soil preparation into stump lifting operation, when the time consumption is only 40 % of the time used for traditional soil preparation. However, in sites where the stumps are lifted, 65 - 90 % of the ground surface is shattered, when in traditional soil preparation the share is only 20 - 30 %. In stump removal sites the natural seeding is more generous than in traditional logging sites and thus the costs of the seedling treatment are higher than usual. At these sites, the amount of deciduous trees is remarkably high, and the great share remains also in first thinning phase. However, this enables the goal-directed co-cultivation of energy wood and log wood. At final felling sites, the canopy and stump collection increases the profitability of the forest cultivation, the estimated cost savings being 45 - 50 € /ha, but the nutrient loss due to the biomass harvesting causes the additional fertilisation costs of 20 € /ha. Especially at stump lifting sites, the higher proportion of deciduous trees increases the seedling treatment costs by 45 - 90 € /ha. However, some amount of deciduous tree growth can be restricted by developing the stump lifting methods. The total benefit of wood production growth after the thinning done in young wood is approximately 100 € /ha, when the nutrient loss is compensated by fertilisation. (Saksa 2008.) The removal of the branches, stumps and big roots reduces the amount of organic matter in the soil and thus changes the functioning of the soil ecosystem. This might be harmful especially in permeable mineral soils (Kuusinen & Ilvesniemi 2008).

8.1.2 Storing

It is likely that the forest biomass is stored at roadside after harvesting. Some amount of the biomass falls at the storage site, the amount being the highest on canopy biomass from which foliage and snapped branches remain at the bottom of the pile. Among the stumps, rocks and mineral soil are carried to the storage. The storing losses of log wood are mainly falling needles and thin branches. Stumps and log wood can be dried in roadside storages even for two summers, but for the canopy biomass the maximal storage time is one year due to the great material losses. (Laitila et al. 2008.) During the storing, potassium and phosphorus may be eroded into water system, if the storages are not covered or if they are situated right next to the ditches. (Helmisaari et al. 2008.)

8.1.3 Effects on soil

The coal balance of a forest is calculated from the difference between growth and reduction. In logging potential calculations, the growth is mainly greater than reduction, and thus forests in general are a carbon sink. Energy wood harvest can affect the carbon balances in future remarkably. Part of the stumps, roots and canopies are taken out, and thus the amount of the organic matter to be stored to the ground diminishes. Its effects have been estimated by calculations, and according to Kareinen et al. (2008), it is likely that the utilisation of the forestry residue in energy production will not threaten the forests' role as a carbon sink and the effect of the energy wood harvesting to the GHG balance is rather low.

The logging residue collection can affect the acidity of soil. The effect on the acidity is based on the nutrient intake of woods and on the outflow of the nutrients attached to

the wood biomass from the ecosystem. If the logging residue is collected as accurately as possible, the drain of base cations increases compared to sole log wood harvesting. Thus, the logging residue uptake may lower the pH of the organic layer in the soil. In final felling sites the pH of humus layer has decreased by 0 - 0,4 units compared to log wood harvesting. This acidification effects have lasted for up to 20 years in some experiment plots. However, the logging residue collection has no acidification effect on the mineral soil and thus the effect on the soil acidity after one energy wood harvesting time remains low. There is not too much information available on the effects of the stump uptake to the physical or chemical features of the soil, such as pH levels, but it may increase the drain of base cations. (Helmisaari et al. 2008.)

During the energy wood collection, more machines move at the logging site than in the traditional logging. In log wood harvesting, the soil compression and the formation of tracks can be prevented by doing the harvesting when the soil is frozen. However, logging residue or stump collection cannot be done during winter time and thus, the machines have to be used also in the time of the molten soil when the damages are caused. When the machines break the soil, the tracks become easily water pits or ditches, and the risk of water erosion increases. Compressing of the soil decelerates the absorption of water into ground, and water may flow in vehicle paths. These drains may also carry solid material into water bodies. Collection of the stumps and thick roots promotes the soil compression, because more machines are needed and more soil is unfolded. The compressed soil can be too tight for the roots of the trees, and it contains very little oxygen. Fortunately, the area in which the machines stir and the damages are caused is relatively small compared to total forest area. (Helmisaari et al. 2008.)

8.1.4 Nutrient balance and fertilization

Nutrients are lost in common disorder situations of forests, being for example forest fire, logging and renewal and renovation ditching. However, harvesting the nutrient-rich biomass calls into question the longevity of the forest soil for the wood production. In thinning cutting, in which the logging residues are also collected, from two to six times more nutrients are taken out from the site compared to traditional log wood harvesting. In final felling the nutrient loss is 1,5 - 4,5 times higher when the residues are collected compared to sole log wood felling. Nitrogen is one of the most essential nutrients for forest growth, and very often the lack of nitrogen is the limiting factor of growth. Even if one third of the biomass is left on site, up to 300 kg of nitrogen per hectare is taken out from the forest among the forest residuals. Nitrogen is present also in soil, but is restored in persistent compounds and thus poorly available for plants. Conversely, nutrients in the logging residues are mainly in the forms available for reuse after a delay time. (Helmisaari et al. 2008.)

The nutrient demand of the woods is the highest soon after the first thinning, i.e. in age of 30 - 50 years depending on the fertility of the soil. The trees remaining after thinning will utilise precisely the nutrients slowly releasing from the residues, but in the forest regeneration site the nutrient requirement remains low for years. Anyhow, the nitrogen leaving among the forestry residue is out from the nutrient circulation, which may affect to the forest growth later on. The growth loss of pine due to the logging residue collection is approximately 7 % compared to growth after sole log wood collection, which is approximately 5 m³ /ha in 10 years. The loss of spruce is around 12 %, which is 17 m³ /ha in 10

years period of time. The surveys indicate regression of growth 3 - 5 years after thinning, i.e. in time when nitrogen would have started to get released from logging residue if it was left in forest. The recovery of growth was not seen in ten-year time period, and the duration of the regression is still unknown. However, different tree species react differently to the logging residue harvesting, and it seems that for example pine is not as sensitive for nutrient loss as spruce. At some peat lands, even in the traditional log wood collection significant share of nutrients can be taken out from the forest. Thus, energy wood harvesting is not recommendable in thick peat soils, which will not get compensating nutrients from mineral soil underneath. (Helmisaari et al. 2008.)

Helmisaari et al. (2008) refers to the research done in Sweden, in which the logging site was observed 15 years after logging. The research detected that the coal-nitrogen ratio was increased (i.e. the amount of the nitrogen was decreased in relation to coal) after logging residue collection. Other foreign studies have discovered that the logging residue collection either has no effect or it has diminished the net mineralisation of nitrogen in long time period. The research done in Central Finland showed retardation of coal and nitrogen mineralisation in humus layer. In addition, some changes in the composition of the organic matter in humus layer were seen. All in all, it seemed that logging residue harvest has unfavourable long-term effects on key features of soil fertility. Therefore, some of the residues should be left on site and distributed evenly in order to maintain the soil fertility. The effect to the nutrient balance of the forest can be compensated by ash fertilisation, which, however, produces some emissions from the transportation and distribution of the ash. (Kareinen et al. 2008).

Wood ash may be used in forest fertilisation, because it contains almost all the nutrients which are bound in wood biomass, except nitrogen and sulphur. By returning the wood ash into the nutrient circulation of a forest, the nutrient loss due to the wood harvesting can be compensated and the acidification of soil stabilised, as the sustainable usage of forest demands. Wood ash is alkaline, so it increases the pH of the top layer of the soil by 1 - 3 units. Thus the ash fertilisation enlivens soil microbes and increases the solubility of the nutrients and the availability of nitrogen. The ash can be pelletized or granulated, which makes the nutrients dissolve slower and the fertilising effect last for decades. The use of wood ash in forest fertilisation has been studied, and its benefits have been proved – especially when nitrogen is added and thus all the essential nutrients are provided. Ash fertilisation has not changed the heavy metal concentrations in berries or mushrooms, nor the soil micro-biota. (Helmisaari et al. 2008.) In this case, it must be mentioned that the ash from the utilisation of torrefied wood pellets in co-firing with coal cannot be used in forest fertilisation if the ash of coal is mixed with wood ash. Traditionally, coal ash has been utilised in concrete production, but mixed ash cannot be used for that purpose either. Thus, the mixed wood-coal ash still needs further investigation in order to find the suitable utilisation way.

Final felling increases the runoff of nitrogen, phosphorus, potassium and solid material into drainage basin. The nutrients are released from organic material: stumps, roots, logging residues, vegetation perished in felling and litter. Good planning of the forest to be cut and the soil cultivation, and the buffer zone can mitigate the nutrient outflow to the water bodies. After a while, when the ground vegetation grows and its nutrient intake increases, the nutrient flow diminishes. Thinning cuttings probably does not increase the nutrient outflow, since the remaining woods bind the released nutrients. In energy wood

harvesting, a remarkable amount of organic matter and nutrients are taken out from the forest, and thus the nutrient flow to the water system is diminished. However, if there are not enough of bigger logging residue fractions are left to bind the nitrogen it can be eroded even more than in traditional logging. Energy wood harvesting may also increase the acidity of forest soil, since among the energy wood also potassium and magnesium is taken out. Furthermore, this causes ascended aluminium and iron concentrations in lakes nearby. It may also cause mercury and lead to dissolve into waters. (Helmisaari et al. 2008.)

Clear-cutting of forest has a remarkable effect on the vegetation per se, and the additional impact of logging residue collection is minor. Small differences in richness of common species between clear-cutting site and integrated clear-cutting and logging residue harvesting do not seem significant. Yet, canopy biomass collection has proved to increase the productivity of planting new trees (Saksa 2008). The sites considered in the Forest Act and other valuable environments are usually left outside loggings, and thus, energy wood harvesting is not done in those sites, either. Forests in a natural state have approximately 60 - 120 m³/ha of deadwood. In a managed forest, the regular thinning cuttings produce small diameter deadwood the same amount that is formed in natural state forests due to natural disruption situations. There are 4 000 - 5 000 different species that are dependent on deadwood, which is at least one fifth of all species. The decrease of deadwood amount due to the efficient forest utilisation has been the most significant side-effect that has caused devolution or endangeredness of the forest species, especially the ones dependent on robust deadwood. Energy wood harvesting diminishes the amount of deadwood and thus the suitable habitats for deadwood dependent species. Due to the thinning of humus layer, logging residue collection affects some soil organisms, which has a further detrimental effect on the forest productivity. (Siitonen 2008.)

If the energy wood from young forests is collected pruned, the biomass accrual would decrease approximately 42 - 46 %. Then the canopy biomass is left on site, but the minimum amount of 25 m³ /ha set for the energy wood harvesting would be hard to achieve. (Laitila et al. 2008.) There is not enough research done about the impacts of organic matter removal for soil biota, forest structure and functioning or the development of new forest. The canopy biomass collection, which is done in the process of thinning of a young forest, causes growth losses in the remaining woods. These losses can be diminished by leaving the needles and some canopies on the site. Similarly, the nutrient loss can be compensated with fertilisation. (Siitonen 2008.)

8.1.5 Sustainable energy wood harvesting

Saksa (2008) sees that as a whole, the effects of forest biomass harvesting to forestry and forest economy can be considered to be positive, since the costs of forestry are diminished and the net profits of forest economy are increased due to the forest chip production. Because the nutrient content of the needles is remarkably higher than of woody biomass, energy wood harvesting causes many times higher nutrient losses than sole log wood collection. The nutrient loss is the highest in the spruce dominating forests, where the canopy yield is the highest. In terms of the effects, the difference is remarkable if the limbed log wood is also collected during the energy wood harvesting, or if the canopy biomass of the final felling site is collected dried. In both of these scenarios, the needles are either left or have fallen on the site. It seems that the growth losses are comparable

to the amount of nitrogen removed from the site. However, the canopy biomass collection gives selling revenues and at final felling sites it enhances the renovation. These compensate the possible economical expenses of the forest fertilization. (Kuusinen & Ilvesniemi 2008.)

The Forestry Development Centre Tapio has established guidelines for energy wood harvesting, based on the precautionary principle. The guidelines consider both the selection of the harvesting sites and the operations at the site. According to new research findings, 30 % of the canopy biomass should be left on site in all conditions. The aspens should not be collected at all because of their importance to demanding species growing in deadwood. Because of the importance of all deadwoods to many species, it should be considered whether the collected and smashed deadwood should be compensated by leaving more trees on site. Lifting the stumps is not soil preparation method, and the proper handling of the ground should be ensured. Many of the environmental impacts of stump lifting relate to great amounts of revealed mineral soil, which should be controlled and not be done in vain. In order to prevent the insect and fungus damages, the energy wood harvesting should not be done in late autumn nor in spring time, the storage piles are built so that in the top layers is only deciduous trees and the canopy biomass is used also to strengthen the soil in places of a risk for sags. In log wood felling, the chemical treatment of the stumps is recommended in the risk areas of fungus infections. In energy wood harvesting this is not currently possible, but it should be done especially in Southern Savonia when harvesting is done in the summer. (Kuusinen & Ilvesniemi 2008.)

The recommendations for sustainable utilisation of the forest resources are based on the data of the resources available. The technical restrictions and criteria for energy wood harvesting sites should also be considered. Thus it is possible that it is not possible to harvest the politically set goal of 12 million m³ of forest chips by following the requirements for sustainable energy wood harvesting. For realistic data, dynamic calculation methods should be developed. The recommendation is that on final felling sites, 30 % of the logging residue is left on site, but in the end it is the forest owner's decision. The more it is gathered, the greater are the revenues, but simultaneously increase the growth losses and other risks. There are pros and cons in energy wood harvesting. The effects are material and immaterial, and become visible during different time periods. In order to increase the harvesting rates, it is crucial that the forest owners are willing to sell the energy wood. To ensure that, the forest owner should get a satisfactory compensation and be aware of the effects of the trade. The forestry sector operators have to be able to ensure that the effects of the harvesting are considered and the risks are managed by following the requirements. The nutrient loss of the logging site can be compensated successfully by using combined wood ash and nitrogen fertilisation. (Kuusinen & Ilvesniemi 2008.)

8.2 Chipping

The production means of the wood chips can be classified according to the chipping location into centralised and decentralised methods. Centralising the chipping to the place of use or terminal enables large annual yield, high utilisation level of the machines and lower chipping costs. However, the weakness of the method is the inefficiency of the transportation of untreated forest biomass. It can be improved by compressing the canopy biomass, pruning the thinning woods and chopping the stumps and roots. Chipping the

stumps and round wood requires heavy-duty crushers and is therefore possible only in centralized chipping facilities. Because of high investment costs, the centralised chipping suits only for large power plants or terminals, from which the chips can be shipped to power plants of different sizes. At the moment, chipping is done mainly distributed, in interim storages, but it is estimated that in near future chipping will be done more and more in terminals, from which wood chips are distributed to the end users and refinement plants. (Laitila et al. 2008.) Chipping is more cost effective when done at the terminal because of the greater volumes, higher utilisation rate and smaller loss. Also, chipping at the terminal decreases the space requirement at the end user site.

The methods of the distributed wood chip production are the harvesting chains based on chippings done either in interim storage or at the felling site. In interim storage chipping method, the load capacity and load size of the truck is fully exploited and the method is also transportation-efficient in long distance transportations. This is the main method when producing forest chips from young forests' thinning sites. In felling site chippings, the chipping and the transportation in forest, as well as the logging in some cases, is done by one machine. Compared to a normal forest harvester, a machine that also does the chipping is more expensive and heavier, because of which the transportation distances in the forest should be short and the ground should be load-bearing and steady. Hence the amount of wood chips produced at the site is very small. (Laitila et al. 2008.)

If small diameter wood, logging residues and stumps are chipped at the terminal or the place of use, the noise nuisance and aesthetical harm are reduced at the logging site. On the other hand, the space demand of the chips is less than of the original material, and thus chipping at the logging site reduces the transportation traffic and the operation days at the forest, which is positive in terms of recreational use of the forest. (Karjalainen & Sievänen 2008.) Logging residues and energy wood should be dried as such, and chipping be done right before the utilisation, since long-term storing is not recommendable. During the long-term storage, processes, such as rotting, growth of micro-organism activity and loss of volatile hydrocarbons, take place and thus the solid mass of wood decreases and increase the dry matter losses. The need for mechanical drying of the wood chips depend on whether the chips are burned as such or refined further to pellets or bio-coal. It is not efficient to dry the chips that are utilised in incineration as such, but the raw material of pellet production or torrefaction process has to be dried up. (Pöyry Management Consulting 2011.)

In Rislog, both chipped and non-chipped wood biomass is taken to the logistic centre, chipped approximately from a < 100 km distance and non-chipped from a < 50 km distance. This is because the transportation of non-chipped wood biomass is not as efficient, and thus the wood should be chipped before long-distance transportation. In the Pursiala power plant area, the chipping is prohibited because of the noise caused by the process, and thus the raw material of the pilot plant is chipped at the logging site.

8.3 Transportation to the torrefaction plant

In the Pursiala pilot plant, the raw material is first taken from the raw material storage of Pursiala power plant, and later on the pilot will purchase its own material. However, the chips are probably purchased from the same suppliers that deliver the material to the

power plant and thus the features of its material supply chain apply also to the torrefaction pilot. According to Jussi Karppanen (2012), the Bioenergy Engineer of Etelä-Savon Energia, the company purchases its wood material from a radius of 60 km from the plant. The transportation is done mainly by road, with full and semi-trailer trucks. The estimation in emission calculation is that the filling rate is 100 %; 40 t for full trailer trucks and 25 t for semi-trailer trucks. In case of the pilot plant, the approximate transportation distance is 30 km. If we assume, that 50 % of the raw material is transported by full trailer truck and 50 % by semi-trailer truck, the total carbon dioxide equivalent (CO₂e) emissions are approximately 7 226 kg per annum, i.e. the whole production time of the pilot plant. However, since it is more efficient to transport by full trailers, the emission rate can be lowered by increasing the usage of them. If 75 % of the material is transported by full trailer trucks, and the remaining amount by semi-trailers, the total CO₂e emissions are only 6 738 kg per year. Also, the transportation distance affects the emissions. If the approximate transportation distance is raised to 50 km, with shares of 50 % for both transportation means, the total CO₂e emissions are 12 044 kg per year. Increasing the share of the full trailer to 75 %, the emissions drop down to 11 230 kg. (See VTT 2012a, VTT 2012b.)

The raw material demand of the Rislog torrefaction plant is much higher than of the pilot plant, and thus the traffic emissions are manifold. However, in the Ristiina bio-logistic centre, the railroad and water way transportation means are also used, both of which are more eco-efficient than road transportation. Lappeenranta University of Technology simulated the procurement logistics of the Ristiina bio-logistic centre with different procurement volumes. Current estimation of the annual raw material volume of the Rislog in its full operation is 1 million m³, of which 50 % is torrefied. At this point, the total volume of the raw material stream to the terminal is so high that all the transportation means, being road, railroad and waterway traffic, are applied. If one third of the raw material demand is transported by trucks, 30 - 40 energy wood and wood chip trucks arrive at the terminal daily; the trucks run 365 days per year. Similarly, if one third of wood chips are transported by train, 1 - 2 trains of 15 cars arrive at the terminal daily. Trains also run year round. Barges pushed by towboats may also carry one third of the raw material demand, and thus will unload the cargo daily in its operating period of 270 days per year. (Pöyry Management Consulting 2011.)

Even though both trains and towboats are more eco-efficient than trucks, i.e. the unit emissions are lower, the transportation distance is likely to be longer. There is sufficiently raw material close by, but the waterway transportation enables efficient raw material transportation from longer distance as well. The possibilities of raw material import from Russia via waterway have been investigated. Many of these details are still not clear, but some estimation is used in the following calculations. One third of total raw material stream transported by road from average distance of 50 km causes CO₂e emissions of 223 000 kg annually. Same amount of energy wood transported by railroad causes CO₂e emissions of 338 000 kg per year if transported from average distance of 100 km. Water way transportation is the most efficient, and the transportation of one third of total from average distance of 100 km causes CO₂e emissions of 310 000 kg per annum. All together the CO₂e emissions caused by the raw material procurement of the torrefaction unit of Rislog in estimated production level are 871 000 kg per year. (See VTT 2007, VTT 2009.)

9 CASE PURSIALA PILOT PLANT

The purpose of this study was to determine the possible environmental impacts of the Pursiala torrefaction pilot plant and the Rislog commercial scale torrefaction plant. The assessment is about to be utilized in the permit processes of the plants. Therefore, the estimations are as accurate as they can be with the limited knowledge and experience of especially commercial scale plants. However, even though there are some torrefaction pilot plants worldwide, the variations of the technologies also affect the emissions and other environmental impacts. Therefore, some of the following environmental impact assessment base on the measurement results of the existing plant, but still they cannot be taken too strictly. Still, I believe, that the suspected environmental impacts of the plants shown in this and the following chapter represent the best available estimation and can thus be used in the permit processes.

Since torrefaction of wood in general is such a new innovation, before building up a large-scale torrefaction plant the technology has to be piloted on a small scale. The torrefaction pilot plant is about to be located in the middle of the existing industrial plants in Pursiala, Mikkeli. In Picture 12, the northern part of the Pursiala industrial area is shown. The red circles point out the existing industrial plants, the rightmost being the ESE power plant. The buildings inside the yellow circle are demolished, and the pilot plant, marked with a blue rectangle, is going to be located on the site of the demolished buildings.



Picture 12 The locating of the pilot plant into Pursiala power plant site (Google Maps 2012)

The background of the torrefaction pilot plant project, the piloting equipment and the environmental impacts and risk assessment of the plant are discussed in the following chapters. Although the pilot plant is about to be built at the end of 2012, not all the details of the equipment or the equipment suppliers have been finalized yet. Heretofore,

negotiations have taken place with two separate companies, first of which supplying the torrefaction apparatus and other the pelletizing unit. The purpose of the piloting plant is to test the process properties and the end product quality, and thus not all the process details or environmental impacts can be known in advance.

9.1 Background

The aim of the pilot project is to build a pilot plant for commercial torrefied wood pellet production, which develops the torrefaction technology and the pelletizing technology of torrefied material. The target of the pilot process is to observe the requirements for raw material and the end product and to particularise the investment costs. Behind the Pursiala pilot plant of torrefied wood pellet production, there is a plan of a large-scale torrefaction plant to be built up in 2015 in Ristiina, Eastern Finland. The pilot plant is planned to be set in Pursiala, Mikkeli, Eastern Finland. The operation of the pilot plant is temporary, ending in June 2014.



Picture 13 Locations of the Pursiala pilot plant (purple spot) and Ristiina bio logistic centre (red spot), area of biomass collection (purple and red circles) and the locations of coal-fired power plants in Finland (Google Maps 2012)

Both the pilot plant and the large-scale torrefaction plant are located in Eastern Finland, near the city of Mikkeli, as seen in Picture 13. The location of the pilot plant is shown in purple and the large-scale plant in red spot. The raw material of the pilot plant is about to be collected from area shown in the Picture, which is at approximately a 60 km distance from the city of Mikkeli. The large-scale torrefaction plant of Ristiina will gather its raw material from a larger area, in the Picture 13 there is an estimated area of 100 km distance shown with red circle. The raw material collection will be discussed in more detail later on. Torrefied wood pellets will be used in coal-fired power plants, most likely at the coast of Finland, where most of the plants are located. One of the Finnish energy produc-

ers running coal-fired power plants participates in the pilot project, and the test co-firing will be done in their plants. Since all the currently coal-fired power plants are potential customers of the commercial torrefied wood pellet production, all currently operating plants in Finland are marked in Picture 13.

9.2 Description of the Pursiala pilot case

The pilot plant is about to be built in Etelä-Savon Energia Ltd.'s Pursiala power plant area in autumn 2012. The purpose of the pilot plant is to produce initial information about the technique and requirements of the raw material for the large-scale torrefaction unit. The production capacity of the pilot plant is about 2 900 t/a, so it is a relatively large-scale pilot. That is because the end product is about to be tested in power plants using coal as their primary fuel. However, the annual production is set to the level on which the environmental permit process is not needed. The piloting project will take from one to two years, the operational time being one year. The project is divided into two phases, the building-up phase (first phase) and the actual operation phase (second phase).

If the building of the pilot plant gets started in autumn 2012, the first phase lasts until January 2013. During the first phase, the installations and the initialization are done. During the initialization, the raw material is taken from the stores of the ESE power plant and the end product is used in the company's energy production. At this point, the focus is on equipment testing and process optimizing, so the turnout is very small and the actual operation starts in the next phase. ESE collects the raw material from approximately a 60 km distance from its power plant. The wood is chipped at a logging site and transported to the power plant by full trailers and semitrailers. The environmental impacts of the raw material collection of the pilot plant are estimated according to this information. At the initialisation phase, it is relevant because of shared raw material collection with the ESE plant, but even though the pilot plant will purchase its own raw material in its actual operation phase, the attributes are assessed to remain the same.

The second phase is the actual production stage. It is estimated to last 12 months, but in case there are some problems in the operation, the process may continue until June 2014. Thus, the operational time of the plant is 17 months at the most. At this point, the pellets are produced for tests to be done in coal-fired power plants volume being approximately 2 900 t/a. The research project is launched for studying the raw material requirements and the quality of the end product for the purposes of the large-scale torrefaction unit. The research project is carried out by Mikkeli University of Applied Sciences and Lappeenranta University of Technology's department LUT Savo Sustainable Technologies.

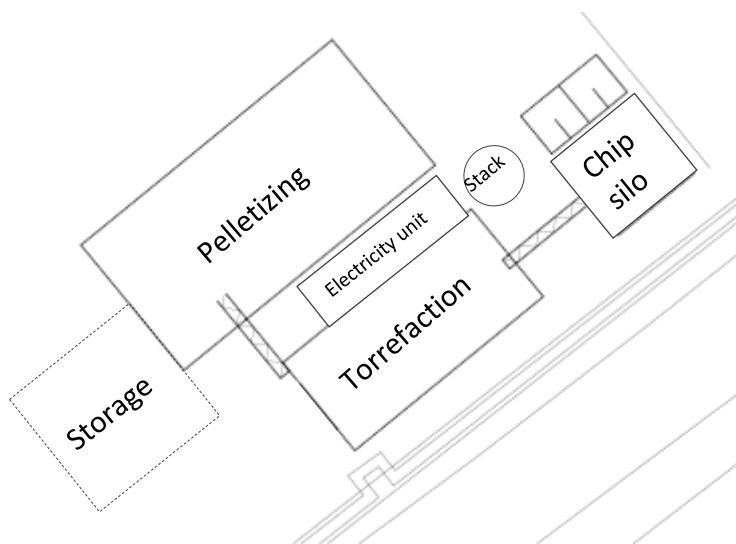
The main goal of the piloting project is to build a commercial scale torrefied wood pellet pilot plant, which can provide valuable research data for a large-scale unit. The objectives are to develop the torrefaction technology of wood bio mass and the pelletizing technology of torrefied material. The suitability of different types of wood raw materials for the torrefaction process and their effects to the end product quality is observed in the research project. In the research project the logistic operations of Ristiina bio-logistic terminal are also modelled and the logistical options of the torrefied pellets from the terminal to end user are demonstrated. The competitiveness of the torrefied pellet is clarified on

the basis of the logistic solutions to be used in the area and the features and cost factors of the Ristiina torrefaction plant. The end product will be tested in coal-fired power plants in Finland.

9.3 The piloting equipment

The pilot plant is located in the ESE's plot, right next to the existing power plant. ESE participates on the piloting process as a co-operator. The process of planning the building up a pilot started in 2011 by looking the possible partners. The equipment suppliers were chosen in late 2011. The pilot scale torrefaction process has been developed by Jartek Ltd., but no contract for building up the pilot plant has been made yet. The pelletizing unit supplier at the pilot plant is most likely Promicco Ltd, though no contract has been made with that company, either. Jartek Ltd. is one of the world's leading wood thermo-treatment equipment manufacturers. The companies have some previous experience in the thermal treatment of wood and its pelletizing. However, the processes will be tested and developed in the Pursiala pilot plant.

Area demand of the Pursiala pilot plant is 50 x 20 m, and compared to the whole industrial area, the plant fits on relatively small area. The layout of the pilot plant is shown in Picture 14. The heights of the units of the Pursiala pilot plant vary from 6 to 9 metres, except for the stack, which is several metres higher. There have been questions whether the pilot plant causes visual harm for example for the Mikkeli Park, which is in the direction of the top left corner in Picture 12. It can be seen that the other existing industrial plants are in front of the pilot plant and thus the visual harm caused by the pilot plant is marginal, and temporary.



Picture 14 The layout of Pursiala pilot plant (Ramboll 2011)

Wood chips are conveyed from chip silo to the torrefaction unit, in which all the phases of torrefaction, from initial heating to solids cooling, take place. After the torrefaction process, the torrefied mass is delivered to the pelletizing unit. There might be need for a

storage silo between the torrefaction and pelletizing, and it could be located next to the pelletizing unit. In the pelletizing process, torrefied material is crushed, and some additives are added before pelletizing. In the pelletizing unit, the pellets are packed into flexible intermediate bulk containers, i.e. big bags. The torrefaction unit is dense when in progress in order to keep up the anoxic conditions, but it can be opened when maintaining the equipment. However, the need for this kind of maintenance occurs only by exception, i.e. if some device damages appear (Piispa 2012). Both processes are run by electricity, and the anoxic conditions are achieved by introducing water vapour into the process to replace oxygen. Water vapour is also used in cooling the biomass after torrefaction to 100 °C. The torrefied mass is conveyed to the pelletizing unit, in which water vapour is taken into process in order to control the flammability and explosion risks. It also constrains the dusting of the material. The water vapour is most probably leaded to gas burner, when it is burned among torrefaction gases and water vapour of torrefaction process, in order to prevent the malodorous air release.

9.4 Environmental impacts of the plant

9.4.1 Emissions to air

During the torrefaction process, water and volatile compounds escape the side products being the process gas and condensing water. According to the Best Available Techniques (BAT) principle, the malodorous emissions can be diminished by efficient collection systems. Burning the collected gas is according to the BAT principle, when the SO₂ emissions are controlled as well. Incineration of the possibly malodorous gases also carries out the odour problems of the plant. (Vasara et al. 2001.) In the pilot plant, the process gas is burned in a natural gas burner and thus the emissions to air are mainly carbon monoxide (CO), carbon dioxide (CO₂) and nitrogen oxides (NO_x), the latter of which is the most significant flue gas of natural gas burning (Jalovaara et al. 2003). By burning the gas, the bad odours are also avoided. Jartek Ltd. has measured the nitrogen oxides (NO_x) and sulphur dioxide (SO₂) emissions in their test plant. The NO_x emissions have been slightly above the limit values, but since the burning process has been remarkably different and thus the burning incomplete, the results are likely to be within the limits in a pilot plant. The SO₂ emissions measured in Jartek's test plant have been under the scale of the metering device. Flue gas burning in general is tested technology in pulp industry, and it is proved to be an efficient way to reduce the malodorous gas emissions (Aunela-Tapola et al. 1996).

In the pelletizing unit, the spreading of the dust is prevented by fabric filters through which all the outgoing air is circulated. All the conveyors are encapsulated, so the material cannot whirl into the air. However, dusting may occur when the torrefaction unit is maintained so that the torrefaction bed is taken out and the remaining solid material on the bottom of the bed gets whirling. The production of the pilot plant does not require the maintenance to be done immediately in case of disruption of the process, and the dusting problem can be minimized by doing the maintenance in proper weather conditions, when the whirling is minimal.

9.4.2 Emissions to ground

The liquid compounds formed in the process are mainly water and acetic acid. In liquid form, these would be the only compounds that could easily absorb into ground, but since they are formed in the process, they are in gaseous form and thus part of the process gas, which is burned. Approximately 30 tons of solid residual is produced during the piloting project. The material is burned in the ESE power plant and thus will not be led to ground. The pilot plant is located near the groundwater zone, but will not cause pollution risk to it. In Vattenfall open air pile storage tests of heat treated pellets, high COD values of leaching water resulted in laboratory analysis (Nordlander 2012). The access of leachate waters to nature can be prevented by installing a blocking layer and proper drainage systems. In the Pursiala pilot plant, however, the pellets will be sacked right after pelletizing, and thus will not be stored in open piles outdoors.

9.4.3 Condensing water

The oxygenless conditions are achieved with water vapour, which acts as an inert in the process. After the post-drying and intermediate heating phase, the water vapour is brought into the chamber and thus the suitable conditions for the torrefaction process are achieved. Water vapour is also used in solids cooling, to cool the material after the torrefaction. Torrefied material is hydrophobic and thus will not be affected by the humidity. The water vapour condensates as the temperature falls under 100 °C during the cooling phase. In the piloting process, approximately 1 m³ of water condenses in a month. The condensing water is acidic; according to the measurements of Jartek Ltd its pH is approximately 2,7. In the Pursiala pilot plant the waste water is either about to be collected to the separate tank, which is emptied frequently, or led to municipal water treatment plant according to a similar type of special waste water management contract as the wood thermal treatment plant nearby.

Condensing water of the torrefaction process also contains dissolved compounds. The BAT limit values for paper and pulp mill for water are 10 - 20 m³/t of consumption, 1,2 - 1,9 kg /t for TSS (total suspended solids), 1,6 - 2,6 kg /t for COD (chemical oxygen demand) and 0,15 - 0,25 kg /t for BOD₇ (biochemical oxygen demand) (Vasara et al. 2001.) Due to similarities in processes, these values can be used as reference values in the torrefaction process as well.

Water vapour is also present in the pelletizing process. However, the water is not condensed, but delivered to the gas burner, in which the vapour is burned to prevent the malodorous release into the air. It is assumed that some substances are released from torrefied biomass into water vapour, and thus the vapour is delivered to the burner. The content of the vapour is measured in the pilot plant, and if it does not contain any malodorous or otherwise harmful substance, the vapour could be released to air through filtration systems.

9.4.4 Noise pollution

The noise level of the torrefaction pilot plant is not remarkable when compared to other industrial plants in the area. According to the manufacturer of the fan engine, the noise level in a 1 metre distance from the engine is approximately 62 - 67 dB (A), depending on the size of the engine. Other noise sources are similar conveyors and unloading equip-

ment as in the ESE's power plant, but on a smaller scale and used only some hours in a day. Thus the noise pollution addition is marginal. In the pelletizing unit, the devices having noise level of 80 - 90 dB (A) in 1 meter off the apparatus are inside the production unit, so outside the unit the noise level is remarkably lower. The pilot plant is used in two shifts at most, so the noise pollution is caused only up to 16 hours a day.

9.4.5 Traffic emissions

During the first phase, the traffic load to the Pursiala power plant area is increased by the delivery and installation of the facilities. At this point, there is no increase in raw material transportation to the power plant site, since the pilot plant takes its material from the ESE's raw material stock and releases the end product back to the power plant's circulation. At the second phase, the production of the torrefied pellet is estimated to be 2 900 tons annually, which means that a total of 6 500 t of wood chips are needed. The amount can also be expressed as 21 000 stères (loose cubic metres), the unit meaning the volume of 1 m³ filled with wood chips loosely, with air between them. The amount corresponds to 175 full trailer loads of raw material in 17 months. On a monthly basis, 10,3 full trailer loads of raw material are received and the end product is shipped in 4,3 full trailer loads. Compared to traffic to ESE's power plant, the increase in traffic load by the pilot plant is marginal. The raw material is transported to the plant from approximately a 60 km distance (Karppanen 2012). The emission effect of the traffic load is handled more precisely in chapter **Virhe. Viitteen lähde ei löytynyt..**

9.4.6 Aesthetical impacts

The pilot plant is situated next to the existing power plant, partly behind the other industrial buildings. The plant is relatively small and neutral in its colouring, and thus will not cause remarkable visual harm. The operation time of the plant is 20 months at the most, from November 2012 to June 2014, and after that the plant is deconstructed and taken away. Therefore, all the impacts of the plant, including the aesthetical impacts, are temporary. There has been discussion about moving the industry in general away from the Pursiala area because of the proximity to the city centre and Lake Saimaa. However, the time scale for this kind of projects is very long, and is not likely to happen in the next decade. Nonetheless, the pilot plant is temporary, and thus will not affect to the overall development plans of the area.

9.4.7 The eco-balance of the plant

In the eco-balance, all the input and output streams of a process are listed. The eco-balance of the Pursiala pilot plant is shown in Table 4. All the inputs and outputs are listed in the table, and the annual amounts of the substances are estimated. It must be noted, however, that the amounts are only estimates, and since the processes are namely about to be tested in the pilot, some amounts are hard to estimate. In the pelletizing process, some additives are added, but since the idea of the pilot process is to test the ideal quantity, the annual input cannot be estimated exactly. The substances and quantities listed in the table are assessed together with the equipment suppliers, and thus represent the best prediction available at the moment.

Table 4 Eco-balance of the Pursiala pilot plant

INPUT	<i>estimated annual amount</i>	OUTPUT	<i>estimated annual amount</i>
Raw material		Production	
Wood chips	6 500 t	Torrefied wood pellet	2 900 t
Energy (mainly electricity)		Waste water	
Torrefaction unit	3 800 000 kWh	Collected separately or lead to municipal waste water treatment plant	
Pelletizing unit	755 000 kWh		10 000 l
Water		Waste	
Torrefaction process	75 000 l	Solid material	1 000 kg
Pelletizing unit	300 000 l		
Gas		Noise	
Natural gas is used for burning the process gases		Occurs max. 16 hours / day, in maximum level of 67 dB(A)	
Packing material		Emissions to air, water or soil*	
FIBC ¹	1500 - 2000 pcs	Dust	20 kg
		CO	120 kg
Chemicals		NO _x **	2 080 kg
Additive a } 1 - 5 % =		SO ₂ ***	400 kg
Additive b } 29 000 - 145 000 kg		TOC	40 kg
		HF	3 kg
		HCl***	170 kg

*) Calculated by multiplying the average of Torr-Coal measurements by ratio of outputs, and multiplying it by annual working hours of the plant (16 h x 250 workdays = 4000 h)

**) The anoxic conditions are achieved by water vapour – no nitrogen is used. Natural gas incineration will produce some NO_x emissions.

***) High SO₂ and HCL contents can be explained by raw material of Torr-Coal torrefaction plant; the contents in Pursiala pilot plant can be expected to be lower.

The torrefaction process is quite simple, and thus no unpredicted material streams outside the list should occur. The additives are used in the pelletizing process, and their quantities in the pellets are about to be tested in the piloting project. All the outputs can be handled by standard methods and no risk to environment should be caused. It must be pointed out that the measurements of the Torr-Coal's torrefaction plant cannot be applied to the Pursiala pilot plant as such because of the process differences. The main differences are the ways in which the oxygen is replaced in the process. In Torr-Coal's plant nitrogen is used as inert gas, which explains the high NO_x emissions. In the Pursiala pilot plant the NO_x emissions are estimated to be remarkably lower, since they are produced only in natural gas burning process, when the atmospheric nitrogen oxidizes.

9.5 Environmental risk assessment of the plant

The operation of the Pursiala torrefaction pilot plant is linked to the Pursiala power plant in many ways. As in the ESE's Pursiala power plant, in the pilot plant only a little environmental harmful substances are handled. In exceptional situations, the procedures of ESE

¹ Flexible intermediate bulk containers (big bags)

are followed. In case of an accident, both the environmental authorities and the citizens living nearby are informed about the situation. The identified risks are handled in several sections: the input materials, the plant and its processes, the activities at the plant, the output materials and the external factors. The possible emission source and its impacts when emitted are listed, and the levels of the probability and consequences are estimated. The estimations were done together with the Biosaimaa cluster coordinator Mika Muinonen. The equipment suppliers were also consulted. The ways to control the risk are listed in the final column. However, it must be pointed out that not all the materials or processes are listed, but only the ones that may have some environmental impact. Thus the tables are not a complete process chart or listing of input and output materials.

9.5.1 Input materials

Materials brought into the torrefaction process are wood chips and water vapour. Natural gas is used for burning the process gas. Pelletizing process uses some additives, named as “additive a” and “additive b”. Water vapour is brought also to the pelletizing process, but it does not cause environmental risk. The machinery requires hydraulic oils, and although the quantities are rather small, oil may have remarkable environmental impacts. Both processes are run by electricity, but no environmental risk is seen relating to electricity input. The environmental risks relating to input materials are shown in Table 5.

Table 5 Environmental risks of the input materials

Emission and its source	Environmental impacts	Probability	Consequences	Operational proposal
Input materials				
Material release in chip truck unloading	Dusting	medium	very low	
Natural gas leak: pipeline breakage, leaks in the joints...	Natural gas release in air	low	low	
Leakage of additive a	Material release → almost no harmful impacts (low toxicity)	low	low	
Leakage of additive b	Material release → no harmful impacts (non-toxic)	low	very low	
Leakage of machinery oils	Oil spill into ground → further to stormwater drainage system	low	low	Preventing straight access to drainage system

According to the classification of environmental risks shown in Table 1 in chapter 3.3 Environmental risk assessment, all the risks related to material input are low risks. In forest chip unloading, the material may dust to environment. However, the amount of dust should be moderate, and the distance rather low. The natural gas is brought in the plant in a tank, and the gas is pressurised. Thus, in case of leakage, the gas will not explode. The gas released to air fade away quickly. Both the additive materials are either low toxic or non-toxic, and thus the consequences of possible emission are rather low. Of input materials, the only remarkable emission source is machinery oil, but the amount of the oil in the process is so low that the environmental risk is considered low.

9.5.2 The plant equipment and the process

The plant equipment consists of storage silos, conveyors, torrefaction and pelletizing facilities, gas burner, bagging equipment and outdoor storage. The operations of the plant are chip silo filling, system control of the pilot plant, additive feed and moving sacks by forklift. In addition, the system control of the Pursiala power plant should be considered because the operations are linked. The physicochemical processes of the plant are the formation of torrefaction gas, condensation of water, dust generation and probably incomplete combustion in gas burner. The risks related to these equipment and processes are listed in Table 6.

Table 6 Environmental risks of the plant equipment and the process

Emission and its source	Environmental impacts	Probability	Consequences	Operational proposal
The plant equipment				
Ignition of the wood chips in chip silo	The impacts of burning; smoke, odour, flue gas	low	low	Circulation time is kept short
Ignition of the torrefied wood in intermediate storage silo	The impacts of burning; smoke, odour, flue gas	low	low	Circulation time is kept short
Breakage of conveyor capsules	Dusting	very low	low	
Air leakage to torrefaction chamber	Ignition or even explosion	low	high	
Problems in filtration system of air	Dusting; release of malodorous air	low	low	
Problems in sacking	Dusting	medium	low	
Problems in sacking	Ignition	low	high	
Malfunction of gas burner	Release of malodorous gases into air	low	medium	
Leaching water; rain water access to torrefied material in outdoor storage	Water of high COD access to ground or stormwater drainage → altered chemical properties	low	medium	Storage of torrefied material done covered
The plant processes				
Chip silo filling	Dusting	medium	low	
Lacks in system control; Uncontrolled process in torrefaction chamber: too high temperature	Ignition or even explosion	low	high	Security system to control the temperature: shutdown of the process
Lacks in system control; Uncontrolled torrefaction process: access of oxygen to the process	Ignition or even explosion	low	high	
Lacks in system control; Uncontrolled conditions in pelletizing unit: insufficiently water vapour	Ignition or even explosion	low	high	
Problems in additive feed	Excess additive into pelletizing unit →	low	low	

	further to drainage system			
Sacks' moving by fork-lift; breakage of sack	Dusting	very low	low	
Chemical processes				
Formation of torrefaction gas; gas release to air	Malodorous gas emission	low	medium	
Formation of condensing water; water release to drainage system	Altered pH balance	low	low	
Dust generation	Dusting	medium	low	Air filtration, no unfiltered air to be released from the process units
Incomplete burning	CO and malodorous gas emission	low	low	

The risks related to the plant equipment and the processes are either low or medium risks. The medium risks are present in operations of high temperature and anoxic conditions, since even a small oxygen leak into the chamber can cause great damage. However, Jartek Ltd. secures the operation by overcompensated humidification and cooling of the process. There are two separate cooling systems, so that double cooling is got if needed, or if the other system is damaged there will still be enough water in the system. (Piispa 2012b.) If the temperature is about to rise too high, the automatic security system will run a controlled shut down of the process.

9.5.3 The activities at the plant

The risks discussed in this section relate to all the activities at the plant, and both human and technical errors take place. Neither of these can be totally prevented, and especially the human error risks are sometimes hard to recognize, but the security systems and education of the personnel can diminish the risk. Some of the main functions in the Pursiala pilot plant are automatic, but some operations are done manually. Thus, the risks relating to activities at the plant are divided into risks of the process control, operation and maintenance. The pilot plant is about to be run in one to two shifts, so communication between the shifts is seen as a place of risk, similarly the communication between several companies operating at the plant is essential for risk-free operation. The risks of the activities are listed in Table 7.

Table 7 Environmental risks of the activities at the plant

Emission and its source	Environmental impacts	Probability	Consequences	Operational proposal
Process control				
Errors in torrefaction process automation	Release of oxygen into process: ignition/explosion	very low	high	
Errors in torrefied material dosing	Need of maintenance → dusting	low	low	
Errors in sacking	Excess dusting	low	low	
Operation				
Human errors due to inadequate orientation of new employees	Almost any kind of hazard: from dusting to explosion	low	high	Adequate training of the employees
Errors in communication between the shifts	Almost any kind of hazard: from dusting to explosion	low	high	Efficient ways to share information
Errors in communication between the companies	Almost any kind of hazard: from dusting to explosion	low	high	Efficient ways to share information
Maintenance				
Maintenance work; opening the torrefaction chamber	Dusting; release of odours	low	low	Doing the maintenance of the torrefaction chamber in suitable weather conditions
Urgent preparations	Dusting; release of odours	low	low	
External contractors: human errors	Almost any kind of hazard: from dusting to explosion	low	high	Proper orientation of the external contractors
Problems in spare parts supply: unintended shutdown of the process	Odour releases of maintenance work	very low	low	

The consequences of human errors are often hard to estimate, since the error can happen in any stage of the process. However, the most crucial errors – e.g. opening of the torrefaction unit when the process is on-going – can be prevented by good safety systems. Education of the personnel and adequate orientation of new employees is essential in risk prevention. The risks are hard to evaluate, since the risk of human error can be minimal or very high – or anything between. However, in this estimation, the operational risks are considered low by their probability and high on their consequences, according to the worst possible scenario. Thus, the risks of operation are medium risks.

9.5.4 The outputs of the process

The outputs of the process are products (i.e. torrefied wood pellets) and emissions and waste materials. Especially emissions and wastes can form an environmental risk if released uncontrolled. The environmental risks of the outputs of the process are listed in Table 8.

Table 8 Environmental impacts of the outputs of the process

Emission and its source	Environmental impacts	Probability	Consequences	Operational proposal
Exiting materials				
Torrefied wood pellets	Odours release	medium	low	Sacking tightly
Emissions to air				
CO ₂	Promotion of global warming	high	very low*	<i>In general, replacing coal by torrefied pellets decreases the total CO₂ emissions</i>
Malodorous gases	Reduction of pleasantness; Irritation of respiratory tract	low	medium	
CO from incomplete combustion	Promotion of ground level ozone formation	low	low	
Dust	Irritation of respiratory tract	medium	low	
NO _x	Harmful health impacts; formation of ozone	high	low	Low NO _x technology adoption
SO ₂	Harmful health impacts; promotion of acid rain	very low	medium	<i>Wood is nearly sulphur-free material → minimal SO₂ emissions if any</i>
Waste water and solid waste				
Condensing water	Altered chemical properties; dissolved substances	low	low	Water treatment (pH neutralisation) before release to drain
Stormwaters	Increased COD	low	low	No rainwater access to torrefied material
Solid residual of torrefaction process ("ash")	Fertilisation impact to soil	low	low	Careful collection from torrefaction chamber → burning in Pursiala power plant
Waste oil	Contamination of soil	low	low	Appropriate handling of waste oil

Some of the emissions have appeared in previous risk tables, such as dust and odour release, but they are also included in this table to examine the consequences of their release to the environment. CO₂ emissions are actually an impact of normal operation, not a risk. Also, when considering the big Picture, the production and use of torrefied wood pellets actually decrease the CO₂ emissions, when coal is replaced in energy production. The risks of the output materials are either low or medium, but with careful handling and adoption of proper treatment technology, many of the emissions can be controlled efficiently.

9.5.5 External factors

There are several factors outside the Pursiala pilot plant that may cause an environmental risk in the plant. Most significantly, the operations at the Pursiala power plant affect the

pilot plant in many ways because of the connection of several operations. The problems in process control at the power plant will most probably have an effect on the pilot plant also. Additionally, the seasons and extreme weather conditions may cause a risk, but also external people and foreign materials in raw material stream can pose a risk. The risks of external factors are listed in Table 9.

Table 9 Environmental risks of external factors

Emission and its source	Environmental impacts	Probability	Consequences	Operational proposal
External factors				
Seasons (heating up or freezing the raw material or the pellets)	Ignition; Increased energy demand	medium	low	The consequences of freezing or heating up the raw material will be clarified during the piloting project
Storms: equipment (conveyors) breakage	Dusting, whirling of the material	very low	medium	Strong capsules
Deluges; water flooding on the piloting plant	Altered chemical features of the water; uncontrolled exit → effects to soil and surface water	very low	medium	High sills; all water should exit via drainage → pre-treatment of water
External people; vandalism → disturb of the operation	Almost any kind of hazard: from dusting to explosion	low	medium	Well controlled access to the plant; minimizing the possibilities for vandalism
Foreign materials in raw material; different heat treatment properties	Uncontrolled torrefaction process; ignition or even explosion	low	medium	Material flow control (e.g. trans-illumination)
Disruptions in power plant operation	Almost any kind of hazard	low	high	

The impact of the seasons cannot be fully estimated beforehand, but the effect should be minimal. If the raw material is frozen, more energy is needed in drying phase, but no environmental impacts other than the ones of the excess energy production, should occur. In the pilot plant, the amounts of stored materials are so low that the risk of ignition can be estimated to be rather small. Storms and water floods would naturally also affect the torrefaction plant. Vandalism is a risk that can be controlled by sufficient security systems. Foreign materials, such as rocks, in raw material can also break the equipment – latest in pelletizing. Since the pilot plant is strongly connected to the power plant, the disruption situations in there would also affect the pilot plant.

9.6 Environmental risk assessment of Pursiala pilot plant

As mentioned previously, the risks are classified according to their probability to expose the receptors and the consequences of the hazard being realised. The risk profile of the Pursiala power plant is shown in Table 10. The number in each box represents the amount of the identified risks in that category. For instance, there are a total of six risks

found, of which the probability of receptors being exposed is medium, and the consequences of hazard being realized are low. The amount of risks in each category will help in seeing the emphasis of the risks, and helps in prioritization of improvements.

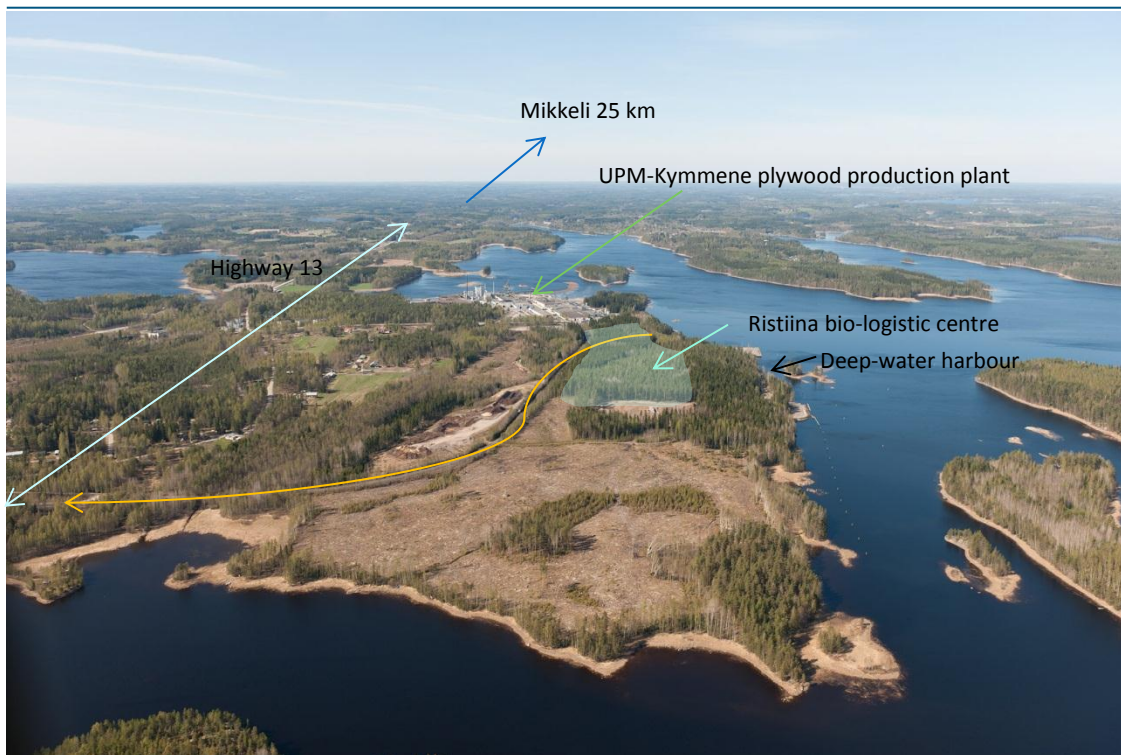
Table 10 The environmental risk profile of the Pursiala pilot plant

Probability of receptors being exposed ↑	High	Medium risk 1	Medium risk 1	High risk 0	High risk 0
	Medium	Low risk 1	Medium risk 6	Medium risk 0	High risk 0
	Low	Low risk 1	Low risk 18	Medium risk 6	Medium risk 10
	Very low	Very low risk 0	Low risk 3	Low risk 3	Medium risk 1
		Very low	Low	Medium	High
		Consequences of hazard being realised →			

The risks of Pursiala pilot plant project are all medium or low risks, and no high risks related to the project were found. The plant is rather small, so the material loads at the plant are low, and no hazardous materials are handled in the process. The highest environmental risks relate to dusting and malodorous releases. In addition, the unexpected situations can cause high environmental risk, such as the access of oxygen into the torrefaction chamber. The technical risks can mainly be prevented in advance with sufficient security systems, e.g. by having more water vapour in the torrefaction chamber than needed. However, the risks of human errors cannot be fully prevented, since those are the hardest to predict. The automation systems of the plant can anyhow prevent the worst possible scenario by disabling some actions when the processes are on-going. All in all, the Pursiala pilot plant seems to have a very small negative environmental impact and a low risk profile, but its benefits can be significant.

10 CASE RISLOG

Ristiina bio-logistic centre ("Rislog") is a bio fuel terminal planned to be built in Pellosniemi area, Ristiina. The Rislog large-scale torrefaction unit is estimated to produce 200 000 tons of torrefied wood pellet per year. The scope of Pellosniemi and the planned area of the bio-logistic centre are shown in Picture 15. The primary function of the terminal is to procure, store and deliver biomass for the needs of the energy production sector. One part of the operation is the refinement of biomass into biofuels, such as torrefied pellets. The location is ideal for bio-logistic centre, since all the transportation means exist at the area already; there is a railway connection, a deep-water harbour, and highways 13 and 15 nearby.



Picture 15 The scope of Ristiina bio-logistic centre (Vallas 2011)

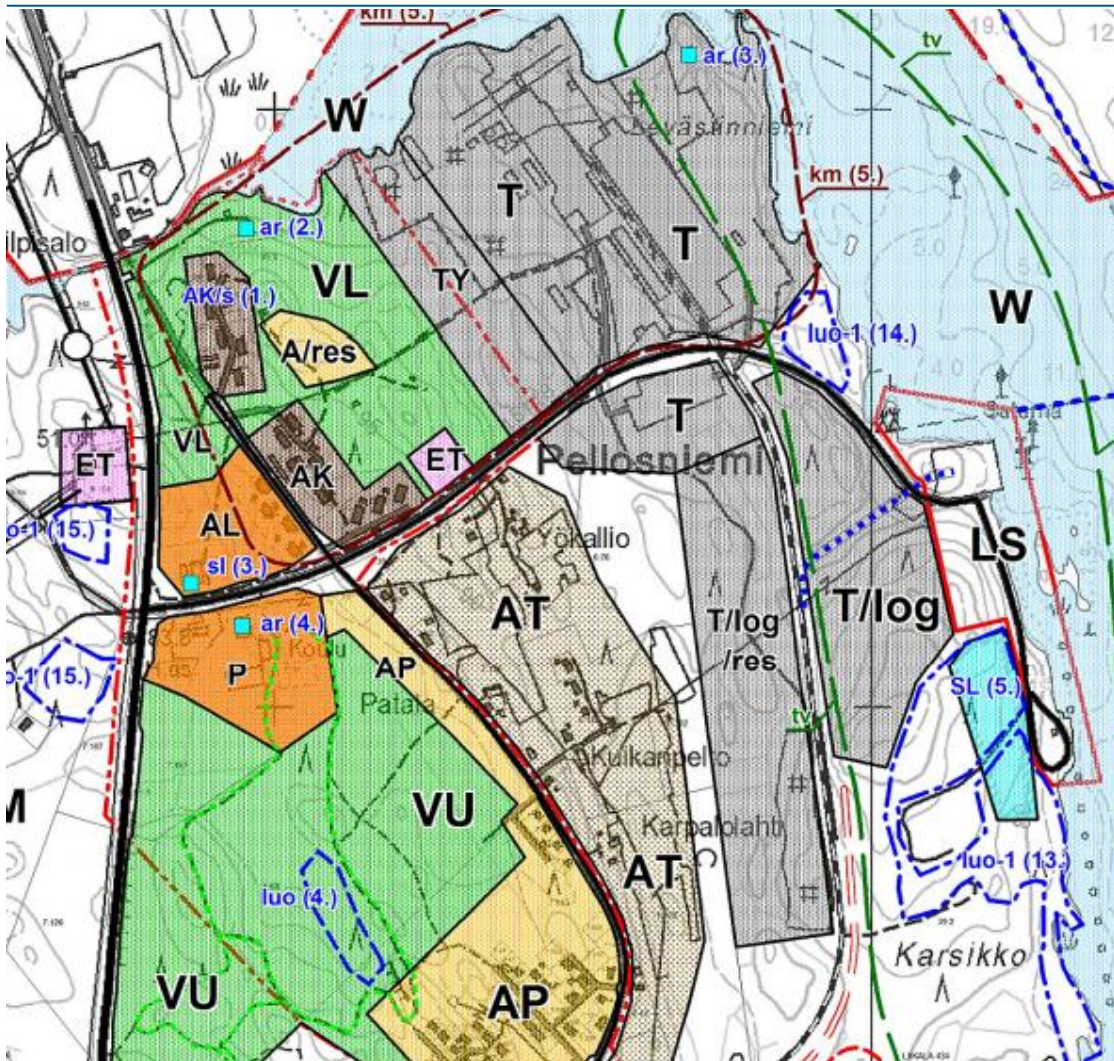
In order to increase the energy density and enhance the handling and usability properties of the biomass, the refinement is needed. The terminal is a natural place for increasing the refinement level cost-effectively. The refinement can either be improvement of the composition and quality, or processing the product. The terminal is also a natural place for mixing the batches of wood fuels, to enable the delivery of as homogenous material as possible to the end-user. The Rislog's annual throughput is estimated to be 1 000 000 solid m³ of wood chips, of which 50 % will be sold to energy producers in approximately 100 km distance as traditional chips, and 50 % will be processed into torrefied wood pellets. These will be sold to coal-fired power plants in Finland, and in the future also to international markets. In terms of raw material supply, the impact area of the Rislog covers whole of Eastern and South-East Finland, but the total sphere of influence is larger if the end users are taken into account as well. According to estimations of Pöyry Management Consulting (2011), the bio-logistic centre is about to employ 25 people at first: 1 on management, 12 on purchase organization, 3 on administration and marketing, and 9 on terminal operations. The forest energy harvesting is organised by contractual subcontracting. The employees of the torrefaction and pelletizing of torrefied wood are not included in these calculations.

The feasibility study of Rislog was done in 2010 and 2011, wherein the raw material supply, logistic options, torrefaction technology and torrefied wood pellet markets were researched. The outcome of the study was that there is potential for profitable business and that the Pellosniemi area is suitable for this kind of operation due to its optimal logistical position. High local raw material potential enables the reliability of raw material supply and the high quality of the end product. Synergy effect with UPM-Kymmene Ltd. plywood plant is also seen as strength. The land use planning and the planning for organising the traffic have started in 2011, and they are about to be completed in 2013. The torrefied wood pellet production is about to be started in Ristiina in 2015.

10.1 The land use planning process

The bio-logistic centre will be built on the southern side of the existing UPM-Kymmene plywood production plant. In the current regional plan and the local master plan, the plot of the centre is considered partly industrial area, partly agriculture and forestry dominated area. There is no valid detailed plan in the area of bio-logistic centre plot, but it is under process. Building up the centre requires valid local detailed plan for the whole revised area, and the planning process is currently in progress. The planning process was started in 2011, and the estimated duration of the process is 2 - 3 years.

The detailed Picture, in which the Rislog bio-logistic centre is shown, of the plan proposal is shown in Picture 16; the complete partial master plan proposal of Pellosniemi is shown in appendix 1. The plot of the bio-logistic centre is marked with "T/log". The bio-logistic operations require an area of 6 ha, and the torrefaction unit an area of 5 ha, the total area of Rislog being 11 ha. The area marked as "T/log /res" is also reserved for the centre, and will probably be used for storing the material. Areas marked with "T" represent the areas of the existing industrial operations. There is a railway connection to the site, and "LS" marks the deep-water harbour, via both of which the raw material, but also the torrefied material, can be transported efficiently. In the Picture 16, highway 13 goes vertically in the left hand side of the map. Currently, the roadway connection to the Pellosniemi industrial area comes through the Pellosniemi neighbourhood. In addition to residence buildings, there is also a nursery and primary schools, gas station and sports hall. Other markings of the plan are described in appendix 1.



Picture 16 The plan of Pellosniemi area (Mäkelä 2012)

There are no areas considered in nature preservation programmes, such as Natura 2000, Nature Protection Programme, or in Southern Savonia regional plan, in the area covered by a detailed plan proposal. Nevertheless, there are several nature value areas, such as an erratic block and valuable basswood forests. These areas are protected, among some other nature areas which are considered valuable. Of the protected animal species, there are several territories of Siberian Flying Squirrel (*Pteromys volans*) within the area. Of flora, one threatened species found from the site is *Carlina* (*Carlina Biebersteinii*), which is considered extremely endangered (EN) in Finland. (Nironen & Vauhkonen 2011.) The protected areas, preserved area of Siberian Flying Squirrel and growth locations of *Carlina* are marked on the map in Picture 16 with blue colour and are considered in the planning process.

In order to improve road safety in the Pellosniemi neighbourhood, especially now when the traffic load is about to be increased, the truck traffic is planned to be moved elsewhere and a new collecting road to be built. Ramboll Ltd. has made a proposal of the alignment of the road. According to the plans, the new road will follow the existing rail-road, and will join to highway 15 roughly 3 km south from the current intersection to highway 13. The new road will begin from the southern end of the bio-logistic centre plot,

follow the railroad, underpass the highway 13 and end up to highway 15 leading to Kouvola; see Picture 17 below.



Picture 17 The situation of the new road (Uuden tien linjaus 2011)

The average daily traffic in 2009 on highway 15 was 1 800 vehicles, and 4 200 vehicles on highway 13. The average truck traffic load on Karsikkoniementie road, which goes through the Pellosniemi neighbourhood, has been 751 trucks daily. It is estimated that the daily traffic load would rise to 6 670 vehicles on highway 13, and to 2 030 on highway 15 in the near future, even without the bio-logistic centre. The traffic load to bio-logistic centre is estimated to be 100 trucks daily. The new road would not affect the traffic loads, but it changes the emphasis of it. The new road would serve also the area on the west side of the highway 13. One benefit is, that the road would not cross the railroad (except if it is done at the bio-logistic centre yard) and that the existing underpass of the highway 13 and the railroad can be exploited. The heavy truck traffic would no longer go through the Pellosniemi neighbourhood, which would increase the safety of the area. However, the road is about to be lined on the bank of Ostolahti bay and thus, building up the road can be expensive. Also, the nature research is still undone, and the environmental impacts of the road still need analyses. (Kinttula 2011.) In any case, the new connection to the highway will most probably not be finished by the time the bio-logistic centre starts its operation, and at first its road traffic will also pass the Pellosniemi neighbourhood.

The plan proposal was available to the public from 12th April to 14th May 2012, and a public event in which the plan was presented to the public was held in April 24th. The dead-

line for possible comments was May 14th and a total of 12 notes were given. Three of these related to the bio-logistic centre, and considered mainly the noise levels of the plant. The negative feedback of plan proposal considered mainly the proposal of a new road connection to the plant. The next phase is the operation and noise level modelling of the bio-logistic centre, in which the changes in noise, compared to current situation, is studied and the noise map is done. This will be done by 28th September, 2012. In areas for holiday housing, i.e. summer cottages, the base value for noise level is lower than in ordinary residential areas. A-weighted average noise level (equivalent level) outdoors in residential areas in the day time (at 7 am to 10 pm) can be up to 55 dB, and during night time (at 10 pm to 7 am) up to 45 - 50 dB. In holiday housing areas, campsites and recreational areas, the limit values are 45 dB (A) at day time and 40 dB (A) in night time. (Ministry of the Environment 2011.) In Pelloosniemi, there are several summer cottage areas nearby the bio-logistic centre plant, and thus the lower limit values have to be met. The existing pelletizing and thermal treatment plants of wood will be used as reference points in noise assessment of Rislog.

10.2 Placement of the plant

Ramboll has made the noise modelling and plant placing plan for the bio logistic centre. The two optional locations of the bio logistic centre and the approximate layout of the plant area are shown in the picture 18 below. The plant layout takes into account the needed buffer stock (approximately 82 000 m³) and the area needed for that, as well as the other requirements of industrial actions.



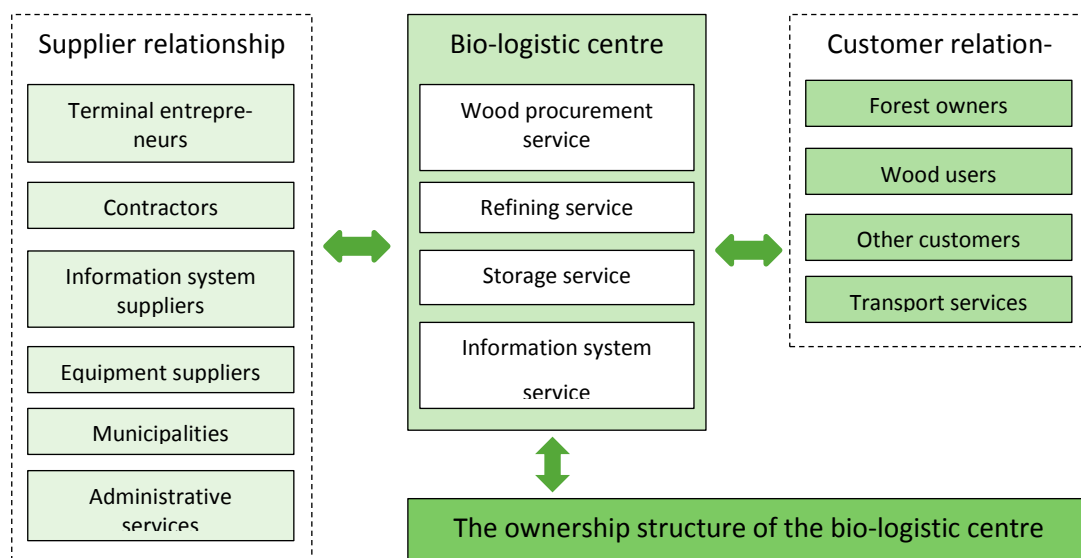
Picture 18 Two optional places and layouts for Ristiina bio logistic centre, the option a on the left hand side and the option b on the right hand side (Ramboll 2012)

Option *a* reduces the aesthetical impacts to summer cottages on the other side of the lake, since the shed of the torrefied material is there in between. The power line has to be shifted, and a lot of quarrying has to be done. The drawbacks of this option are that there are no natural or constructional noise barriers on the west direction, and the location of the wind mill is problematic. However, product shed, crag and slope act as a barrier on south-east direction, and the bio logistic centre would be close to the deep water harbour. (Ramboll 2012.)

In the option *b*, the shed of the torrefied pellets acts as a barrier towards the settlement on west. In this option the road connection would be on the “wrong side” of the railroad, and thus there is need for a level crossing. Also the distance to the deep water harbour is longer. Also in this option the power line has to be shifted. Both of the options enable expansion of the plant on the south. (Ramboll 2012.)

10.3 Description of the case

The bio-logistic centre will operate in forest energy markets. It offers the refinement and purchase services of wood-based fuels for energy operators. Its main function is to deliver the wood fuels through the terminal or straight to customer, processing of the wood fuels at the terminal by chipping, crushing and drying, and possibly also by torrefying the bio-mass. It is going to be a buffer stock of biofuels and thus, the energy producers will not have to reserve so much space for raw material storage. In the future, the bio-logistic centre could also deliver raw wood to the local saw industry operators. The operation of the bio-logistic centre consists of several functions: wood chipping services, storing of forest energy in main terminal and in satellite terminals, providing of administration, co-ordination and information services. In addition, there will be a transfer service of round wood and refinement services of wood fuel into torrefied wood pellets. Some of the services could be outsourced to service providers. The stakeholders of the bio-logistic centre are shown in Picture 18. The network of stakeholders is relatively wide, and thus the stakeholders are classified according to the clearest division to wood fuel buyers and sellers. (Pöyry Management Consulting 2011.) At the moment, the ownership structure of the bio-logistic centre is still open.

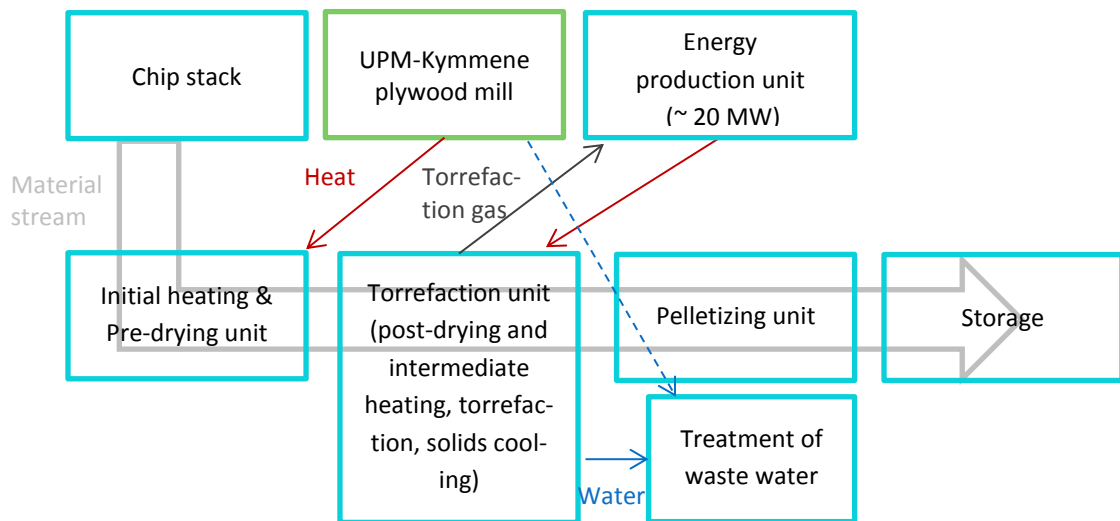


Picture 19 Stakeholders of the Rislog (Pöyry Management Consulting 2011)

It is not yet clear, how wide the scope of services will be, and how widely the bio-logistic centre will involve for example in the wood procurement and forest management, but it should cover the whole value chain of forest energy. Though the torrefaction unit is one

single part of operation of the Ristiina bio-logistic centre, only the processes and impacts of it are examined in this study.

There is no layout plan of the Ristiina bio-logistic centre or its torrefaction unit yet. The next phase in the process planning is the noise modelling of the plant, which will be done in autumn 2012, and after that the arrangement of the plant can be planned. The general structure of the plant is known, however, and is shown in Picture 19.



Picture 20 The general structure of Rislog torrefaction unit

The synergy effect of UPM-Kymmene Ltd. is exploited in heat transfer to the initial heating and wood chip drying process. At this point, the wood pellets are dried to a moisture content of 10 - 15 % depending on the drying equipment. Then the dried biomass is conveyed to the torrefaction chamber. The energy production unit of the torrefaction plant offers heat to the torrefaction process by combustion of torrefaction gases. Though the torrefaction process is likely to turn exothermic, and the energy demand is thus low, it is prospected that the torrefaction process gas solely will not produce enough of energy, and thus it will be incinerated with wood chips. The material stream goes through same steps as in piloting plant, but one of the main differences is the separation of the biomass heating and drying unit, and the torrefaction unit. Another synergy benefit with the UPM-Kymmene plywood plant can be the treatment of waste water.

10.4 The research project

A research project about the feasibility and profitability of the Ristiina bio-logistic centre was implemented in 2010 – 2011. The project was implemented by the Municipality of Ristiina, and the expert services were provided by Miktech Ltd. The business plan was done by Pöyry Management Consulting. The steering group consisted of representatives of several stakeholders. The research project was funded by the European Regional Development Fund. The aim of the project was to find out the needs of customers and oper-

ators, the material flows and raw material availability, the possibilities to increase the refinement level, and the space requirements of the centre. During the project, the initial functional planning and land cropping, simulation, and the business plan of the plant were also made. In addition, Lappeenranta University of Technology compiled a market research of bio-coal pellets, i.e. torrefied wood pellets. The project included an excursion to the Netherlands, to one of the few operating industrial scale torrefaction plants. The municipality started the land use planning and the zoning process during the project in early 2011. The negotiations took place with various parties, which could be the owners or customers of the planned logistic centre. The project was found interesting, and further discussions will be conducted. The Finnish Transport Agency and VR Transpoint were consulted about the traffic arrangements.

The bio-logistic centre will increase the employment significantly in Southern Savonia through the whole energy wood supply chain and provide new business opportunities for small and medium-sized enterprises (SMEs). The research project concluded that there are premises for successful business of a bio-logistic centre, and that there is an excellent plant for the centre with a good logistical position, which enables road, rail and waterway transport. The plant is located next to the plywood production plant and thus suits the planned operation very well. According to the raw material supply research, there is sufficiently raw material in the local area, and the acquisition zone is possible to be extended by waterways. Sole terminal is not seen as profitable, and the refining of biomass is required for cost-effective business.

Torrefied wood pellets seem to be the most promising biofuel. There are international markets for torrefied wood pellets, even though there is still no large-scale production. The production technology is developing fast, and the development will still take some time, as well as the international standardization. However, energy producers have shown interest in the project, and some of them could be the owners or customers of the Ristiina bio-logistic centre. It is probable that the first torrefaction plant in Finland will get the investment grant of the Ministry of Employment and Economy, and thus the implementation of the project should be done quickly. The project objectives were achieved as planned, but more detailed plant engineering is needed for the investment decision of the operators, so that the investment and operating costs can be examined more closely.

10.5 Connection to the pilot plant project

The Pursiala pilot plant is a central part of project Rislog. The technological features of the Rislog torrefaction plant are not necessarily equal to the structure of the pilot plant, nor is it said whether the technology supplier is the same. However, the purpose of the pilot plant is to provide information for large-scale plant planning. The idea of the piloting plant is that the technologies and operations can be tested on a small scale before launching the large-scale unit. The technological alternatives and operational changes can be tested easily in a small unit. The duration time of the torrefaction process can be easily altered with small material volumes, and similarly also the different additives and their impact to end product quality is easy to experiment. The key purpose of the pilot project is to find out the raw material and end product properties, and end product suitability to co-firing in coal-fired power plant. Primarily it is assumed that the same equipment supplier(s) will operate in both plants.

10.6 Environmental permit policy of the Rislog plant

The EIA process is not necessarily needed in Rislog's case, and the environmental impacts can be assessed for instance in the land use planning process. According to Panula-Ontto-Suuronen (2012b), EIA is not required for the Ristiina bio-logistic centre, because only approximately 2 km of new road is built, and the power plant of the torrefaction unit is rather small. A solid fuel production plant in general does not require EIA procedure. There are also wind turbines planned to be built at the site, but only two, and the EIA is required for wind power plants of 10 turbines and more. Also, the positive impacts of the torrefaction, i.e. replacing coal in energy production, and the new road connection, i.e. shifting the traffic away from the residential neighbourhood, should be considered. In principle, the application of EIA procedure to environmentally benign projects is questionable. Originally, the purpose of EIA was to compare different locations for the process. At this point, the location is already known, and thus the EIA is not seen necessary either in that sense. As mentioned previously, the public hearing of the project was held in spring 2012, and 12 notes were given about the plan proposal. When considering the large amount of land owners in the area, the amount can be seen as remarkably low. Having the EIA procedure or not will not affect the ability to appeal against the process, but it may diminish the doubts on the project. Though the Special Planner of Centre for Economic Development, Transport and the Environment sees that the EIA procedure is not needed, if a resident of the area asks for the procedure, it has to be done.

The road project is the most complicated, and it gathered several comments from land owners. It is not clear yet whether the road is going to be built by the state, or if the municipality have to make it. It seems that the road project will take more time than planning the bio-logistic centre, and at first the existing road connection will be used. The Pellosniemi School is under the threat of closure, and it is not sure whether there still is a school when the centre starts its operation, but in any case the road safety of the residential area will be improved when the traffic is shifted away. Road safety is not considered in EIA and is not an environmental issue but a social factor.

According to the Environmental Protection Act (86/2000), the environmental permit is required always when producing solid fuels. Though the EIA procedure is not required for gaining the permit, the environmental impacts have to be estimated. Utilisation of natural resources is one of the permit premises, but the level is rather low, and this could be taken in to consideration if there were these kinds of plants nearby already. Nevertheless, it is hard to find any better place for this kind of operation, and thus the environmental permit is most probably given to the plant. The process structure should be clear when applying for the environmental permit. The application can be complemented afterwards, though the system goes more smoothly if all the information is available in the first place. (Panula-Ontto-Suuronen 2012b.)

The permit process can take a total of 1 - 3 years, but the permit can be given in 10 - 12 months if all the research is done in advance. However, in the case of new plants, the process is aimed to be handled more rapidly. The permit process can be started even before establishing the company running the Rislog, and the permit can be shifted to it once it is established. The permit process does not have to wait either the land use plan pro-

cess to get ready, since it can be said that the operation is about to take place at an existing plant. The planning process can take two years, and the permit process another two years. When there is a sort of race for building up the first large-scale torrefaction plant in Finland, waiting for the completion of the land use planning is not reasonable. (Panula-Ontto-Suuronen 2012b.)

10.7 Environmental impacts of the plant

Since many of the environmental impacts of the Rislog large-scale torrefaction plant are the same as in the Pursiala pilot plant, though on a different scale, mainly the differences to the case pilot plant are presented. Also, it must be pointed out that the estimations of the environmental impacts of the Rislog torrefaction plant will clarify as the piloting plant starts its operation and the equipment and the operations get tested. In the piloting plant, the measurements and analyses of for example the composition of the process gases or condensing water, and thus the estimations for the large-scale unit can be clarified.

10.7.1 Emissions to air

As in the pilot plant, in the Rislog torrefaction plant the torrefaction gases are also about to be burned. However, in Ristiina, the gases are utilized in the energy production of the plant, and thus the energy demand of the plant is likely to be covered by the process gas incineration. In that process, the emissions to air are mainly CO₂ and CO, and most probably the NO_x are low. Because wood does not contain sulphur, the SO₂ emissions are likely to be low – if there are any. Similarly as in the pilot plant, the dusting is about to be prevented by effective filter systems and encapsulated conveyors.

10.7.2 Emissions to ground

The liquid substances formed in the torrefaction process are taken into incineration among the process gases, as in the pilot plant. Thus, the possible emission sources to the ground are mainly the solid residue of the process, or the torrefied wood pellets, if stored outdoors. In the piloting process, the solid residue of the torrefaction process is tested, and the end use for the material is developed. The treatment of the solid material will be clarified when its properties are known. If no efficient way to utilize the material is found, it can be burned in the energy production unit of the plant. Thanks to Vattenfall tests, the torrefied material will not be stored outdoors without having a blocking layer between the material and soil. The torrefied pellets will be stored in stacks, in shelters. The ground under the stacks will be covered.

10.7.3 Condensing water

As in the pilot plant, the water vapour is used to replace oxygen in torrefaction chamber. Since the torrefaction and the solids cooling are done in the same chamber, the vapour condenses in the cooling phase. According to estimations of Jartek Ltd. representative Kimmo Piispa (2012b), approximately 400 m³ (400 000 l) of water condenses annually. However, this depends largely on the torrefaction chamber and operation properties, and thus is only a rough estimation. Pelletizing process in pilot plant will clarify the treatment

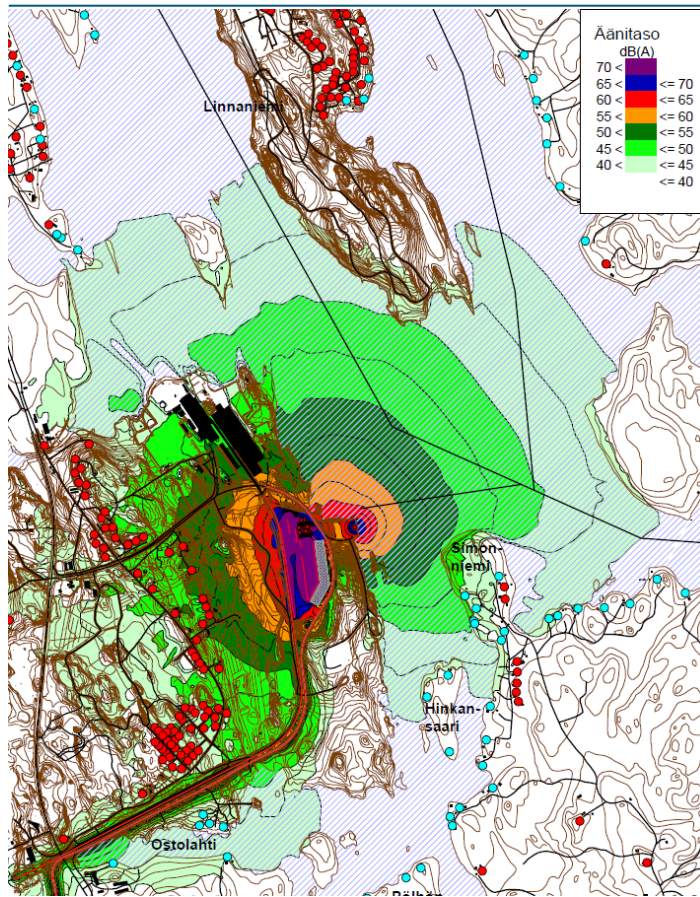
of the water vapour used in the pelletizing process, but the estimate is that it is burned also in Rislog among the torrefaction gases. The waste water treatment can be handled together with the UPM-Kymmene plywood plant, or it can be collected separately and treated separately before transportation to municipal waste water treatment plant.

10.7.4 Noise pollution

Ramboll has made a noise modelling for the bio-logistic centre and its key operations. The modelling was done by using the same initial data as used in this report. The results of the noise modelling were analysed according to the limit values for noise nuisance. The 3D-noise modelling programme takes into account the ground surfaces, contours and buildings. It also considers the distance and the noise fading. The noise modelling was done for both of the placing options, so that the chipping equipment was and was not included. The model does not consider the raw material piles or the torrefied material piles, since they are likely to change. Neither the woods were taken into the calculations, though the forest zones do buffer the noise pollution, but their situation may change due to a thinning or final felling.

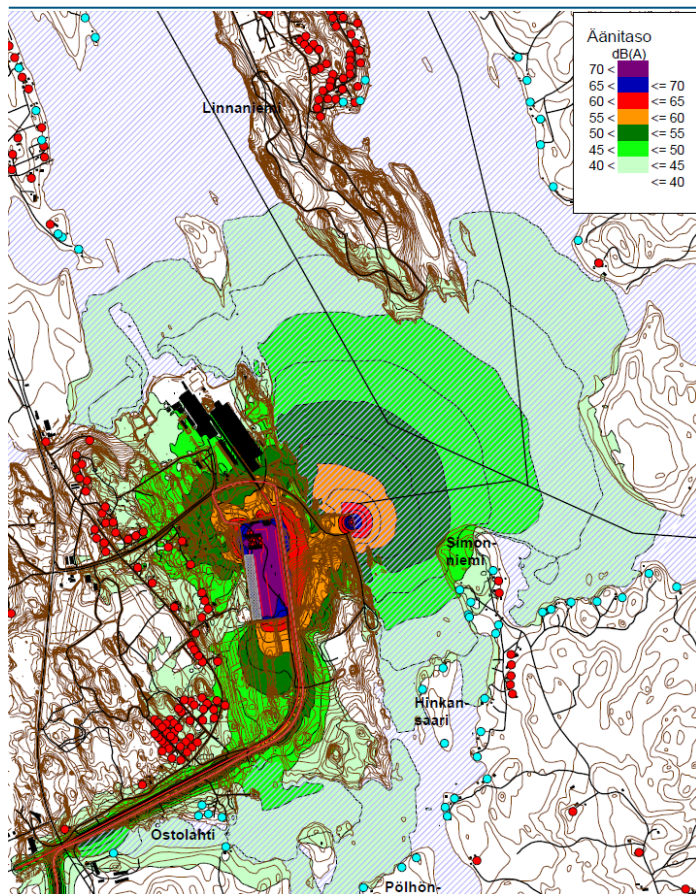
The model estimates that there are two separate torrefaction units in Ristiina bio logistic centre, both producing 100 000 t of torrefied material annually. The noise modelling took into account the noise sources of these torrefaction and pelletizing units, the conveyors, heat production, wheel loaders and forklifts and material handling at the deep water harbour. The model also considers the noise of road and railroad traffic. It was assumed that the raw material is shipped to the bio logistic centre by energy wood trucks and trains. Torrefied wood pellets are transported to end-users by barges and wood chips by trucks. In addition to the bio logistic centre's traffic noise, the road traffic of the UPM-Kymmene plywood plant which is about to be directed to the new road were also taken into account.

As this report concentrates only on the environmental impacts of the torrefaction plant of Rislog, only the noise modelling results without the chipping equipment are presented here. These results contain also some noise sources outside the torrefaction process, and the actual noise levels of torrefaction plant are most probably lower.



Picture 21 Noise modelling of option *a* (Ramboll 2012)

In placing option *a*, shown in Picture 21 above, at some summer cottages (blue spots) the day time noise is on reference value level of 45 dB(A). In permanent residence areas (red spots) the day time limit value is higher, 55 dB(A), and the noise caused by the plant is less than that. At night time, when assuming that the torrefaction plant runs round the clock, the night time limit value of 40 dB(A) is exceeded at some summer cottages on the other side of the lake. At most of the summer cottages, the night time noise level is within the limit values when considering the calculation uncertainty. On the western side, at the nearest residential buildings the noise is about 50 dB(A), which is the night time limit value, but not higher.



Picture 22 Noise modelling of option *b* (Ramboll 2012)

Noise modelling of the placing option *b*, shown in Picture 22 above, resulted day time noise levels of 45 dB(A) at summer cottages on the other side of the lake, and at the residential areas less than day time limit value of 55 dB(A). In this option, at some points the night time limit value of summer housing areas is exceeded, and at many summer cottages the noise is at 40 dB(A) limit value level. At the nearest residential buildings on the west side, the night time noise level is close to reference value of 50 dB(A), and elsewhere less than that.

When considering the current noise situation at the area, the bio logistic centre affects mostly the areas on the other side of the lake from the deep water harbour. According to the noise modelling, the noise impacts on the nature are higher in option a. The noise effect on areas close to the highway is minor, except at night time when the normal traffic of the highway is less, and traffic noise is caused mainly by the bio logistic centre's operations. At some points, the reference noise levels are exceeded due to the bio logistic centre's operations. The noise emissions can be restricted by limiting the night time loading at the harbour, and by building noise barriers between roads and residential areas.

10.7.5 Traffic emissions

Ristiina is relatively far from the coal-fired power plants in operation, and thus the truck transportation can be both expensive and non-eco-efficient. Not all the coal-fired power plants have an existing railroad connection, so train transportation cannot be utilised in every case – at least not as the only means of transportation. The deep-water harbour is a clear trump for Rislog, since most coal-fired power plants are located in the coast side.

However, ship traffic cannot run year round, and at least in winter time other options have to be available. In Ristiina, there are both trains and trucks operating year round. In terms of environment and the emissions, ship is clearly the best means of transportation due to its efficiency and it should be considered to be the primary option. Train and barge are also the most cost-effective transportation means, the transportation costs being more than 60 % less per m³ than the cost of truck transportation in 100 km distance (Pöyry Management Consulting 2011). Nevertheless, it is much cheaper to transport the torrefied fuel than untreated wood biomass due to its high energy density, and thus the refinement close to the raw material harvest area is reasonable.

Ristiina bio-logistic centre and its torrefied wood pellet production will obviously increase the traffic load and traffic emissions at the Pellosniemi area. In any case, it is hard to imagine a more suitable location for this kind of operation: there is the largest biomass potential in the country near to the centre, and all the main transportation means available. Transportation of untreated biomass is far less efficient than that of treated one, and thus it is wisest to process the biomass close its source. Therefore, it seems, that the traffic emissions of Ristiina bio-logistic centre and thus torrefied wood pellet production are among the smallest possible in Finland.

10.7.6Aesthetical impacts

The most remarkable aesthetical effect of Ristiina bio-logistic centre is caused by the wind turbines planned at the site. However, these are separate project to torrefaction plant, and will not be discussed in more detail at this point. The buildings of Rislog will be normal industrial constructions, the highest part being the stack of the energy production unit. The aesthetical harm is experienced mainly on the other side of the lake, from which, however, the existing industrial plants are already seen.

10.7.7The eco-balance of the plant

The eco-balance of the Rislog torrefaction plant bases largely on the eco-balance of the Pursiala pilot plant. However, even with the same equipment suppliers and process features, the differences will be remarkable when operating continuously, in large-scale. The operation will be more efficient and the emissions most probably reduced in relation to production. The eco-balance of the Rislog torrefaction unit is shown in Table 11 below.

Table 11 Eco-balance of the Rislog torrefaction plant

INPUT	<i>estimated annual amount</i>	OUTPUT	<i>estimated annual amount</i>
Raw material		Production	
Wood chips	450 000 t	Torrefied wood pellet	200 000 t
Energy		Waste water	
Torrefaction unit*	200 000 MWh	Collected separately or lead to municipal waste water treatment plant	
Pelletizing unit	40 - 60 000 MWh		400 000 l
Water		Waste	
Torrefaction process	4 000 000 l	Solid material	10 000 kg
Pelletizing unit	20 000 000 l		
Chemicals		Noise	
Additives	2 000 - 10 000 t	Noise modelling will be done in autumn 2012	
		Emissions to air, water or soil**	
		Dust	1 490 kg
		CO	7 950 kg
		NO _x ***	138 600 kg
		SO ₂ ****	26 330 kg
		TOC	2 480 kg
		HF	200 kg
		HCL****	11 430 kg

*) Includes the energy used for drying the biomass

**) Calculated by multiplying the average of Torr-Coal measurements by ratio of outputs, and multiplying it by annual working hours of the plant (24 h x 360 days = 8640 h)

***) The anoxic conditions are achieved by water vapour – no nitrogen is used. Natural gas incineration will produce some NO_x emissions.

****) High SO₂ and HCL contents can be explained by raw material of Torr-Coal torrefaction plant; the contents in Rislog torrefaction plant can be expected to be lower.

As the process gets tested in the pilot plant, the eco-balance of Rislog torrefaction unit will be clarified. The plant planning and noise modelling of the plant will help in some assessments. However, it is already known that no natural gas is taken into process, since the process gases will be burned as such or together with untreated wood chips. The end-product will not be shipped in sacks, but most probably in bulk.

10.8 Environmental risk assessment of the plant

The risk assessment of Rislog torrefaction plant is similar to the assessment of the Pursiala pilot plant by some aspects. The planning of the Rislog torrefaction plant has not started yet, and so not all the technical details are known, but some general differences to the Pursiala pilot plant will be seen. One of the main differences to the pilot plant is the input of heat to the process, by which the wood chips are dried and the torrefaction process is run. Environmental risk assessment of the Rislog torrefaction plant will get more accurate as the pilot plant starts its operation and the experiences of it are gathered. However, some of the environmental risks of the plant can be estimated. The environ-

mental risks of the Rislog torrefaction plant, which differ from the ones of Pursiala pilot plant, are listed in the following section.

The difference to the pilot plant in input materials is that no natural gas is used in torrefaction gas burning, and thus the risk related to it is not valid in Rislog torrefaction plant. However, heat is taken into the process, and there is a risk mainly for employees of the plant. The differences in risks of the Rislog torrefaction plant to the risks of the Pursiala pilot plant are shown in Table 12 below. The risks written normally are additional risks to the pilot plant's ones, and the ones of strikethrough are the risks of the pilot that do not exist at the Rislog plant.

Table 12 Environmental risks of Rislog torrefaction plant

Emission and its source	Environmental impacts	Probability	Consequences	Operational proposal
Input materials				
Breakage of heat pipelines	Risk of burns (employees)	low	low	
Natural gas leak: pipeline breakage, leaks in the joints...	Natural gas release in air	low	low	
The plant equipment				
Problems in initial heating chamber: external compounds	Ignition; Odour release	low	low	
Problems in process gas incineration and heat supply	Slowdown of the process; Odour release	low	medium	Co-incineration of process gas with wood chips → continuous process
Problems in sacking	Dusting	medium	low	
Problems in sacking	Ignition	low	high	
Malfunction of gas burner	Release of malodorous gases into air	low	medium	
The plant processes				
Sacks' moving by fork-lift; breakage of sack	Dusting	very low	low	
Process control				
Errors in sacking	Excess dusting	low	low	
Operation				
Errors in communication between the companies	Almost any kind of hazard: from dusting to explosion	low	high	Efficient ways to share information
External factors				
Disruptions in heat supply from UPM-Kymmene plywood mill	Increased demand for torrefaction plant's own energy production: emissions of secondary fuel incineration	low	low	Co-incineration of process gas with wood chips → Carbon dioxide neutrality of secondary fuel
Disruptions in power plant operation	Almost any kind of hazard	low	medium	

Though many of the risks are similar with Pursiala pilot plant, some differences occur as well. The risk analysis clarifies among the finalization of planning of the Rislog bio-logic

centre and the torrefaction plant. The pilot plant gives valuable information also about the risks, and those can be taken into account in the planning process of Rislog large-scale unit and thus be prevented in advance. Since some of the risks of the pilot plant do not take place in Rislog, the risk profile is somewhat different. The environmental risk profile of Rislog torrefaction plant is shown in Table 13.

Table 13 The environmental risk profile of Rislog torrefaction plant

Probability of receptors being exposed ↑	High	Medium risk 1	Medium risk 1	High risk 0	High risk 0
	Medium	Low risk 1	Medium risk 5	Medium risk 0	High risk 0
	Low	Low risk 1	Low risk 19	Medium risk 5	Medium risk 8
	Very low	Very low risk 0	Low risk 2	Low risk 3	Medium risk 1
		Very low	Low	Medium	High
		Consequences of hazard being realised →			

Despite some differences, the risk profile of the Rislog torrefaction plant seems very similar to the one of the Pursiala pilot plant. In general, this kind of operation will not cause remarkable environmental risks, when planned properly and utilising the newest technology. However, it must be pointed out once again that the decisions of the technology of the Rislog torrefaction unit have not been done yet, and the environmental impact estimation and the risk assessment will clarify as the process properties are finalized. Still, when considering the process in general, the impacts should not be hazardous nor the risks intolerable.

11 DISCUSSION AND CONCLUSIONS

Torrefaction is one of the most promising ways to process biomass so that it can replace traditional, fossil energy sources. It enables biomass utilisation in existing power plants, which is the most efficient way to increase the share of renewable energy sources. Forest biomass processing is most efficiently done close to its source, that is, the forest. Especially in case of torrefied wood material, long distance transportation is far more efficient than of the untreated biomass. In Southern Savonia, there is the largest forest biomass potential in Finland, i.e. there is a lot of raw material available for torrefied wood pellet production. The refinement of wood fuel in the region seems very reasonable, and it would also bring financial value to the region. The project's impact on employment is remarkable. In addition to the benefits on the local economy, the project would have national value as well. When replacing the fossil fuel, in this case coal, by a wood-based energy source, the need of fuel import and carbon dioxide emission permit are reduced. Globally, the carbon dioxide emissions are decreased, and global warming is slowed down.

Testing the process properties and the equipment on a small scale is crucial for building up a functional large-scale torrefaction plant and production of the best possible torrefied wood pellet by its features for coal co-firing. The Pursiala pilot plant will be a relatively large-scale pilot, so that the testing of the end-product can be done in the existing coal-fired power plant, at its actual operation level. Thus, the pilot plant will produce highly valuable information for large-scale unit planning, in order to optimize the process features. The most significant environmental impacts of the pilot plant are dusting and release of substances after process gas burning in gas burner, namely nitrogen oxides, carbon dioxide and carbon monoxide. The highest environmental risk at the plant relates also to the process gas burning. In case of malfunction of the gas burner, malodorous gas can be released to air. Process gas burning is a common operation in wood thermal treatment and pulp industry, and thus the best practices of odour release prevention can be adopted from both of these industries.

In Pellosoiniemi, Ristiina, there is already an ideal infrastructure for bio-logistic operations and wood processing, as there is a railroad connection and deep-water harbour at the site already. Building up a bio-logistic centre and large-scale torrefaction plant would require only building up a new connection to the main road, but otherwise the location is superior for this kind of operation. The land use planning process of the plant is on-going, and the plant planning and noise modelling will be done still in autumn 2012. The aim of the pilot project is to clarify many operational uncertainties of the large-scale torrefaction plant, and thus before gaining the experience from the pilot plant, not all the environmental impacts of the Rislog torrefaction plant can be estimated. The main environmental impacts of the plant will be the same than of pilot plant, but when considering the environmental effects of the total process, the reduction of coal utilisation in energy production should be taken into account.

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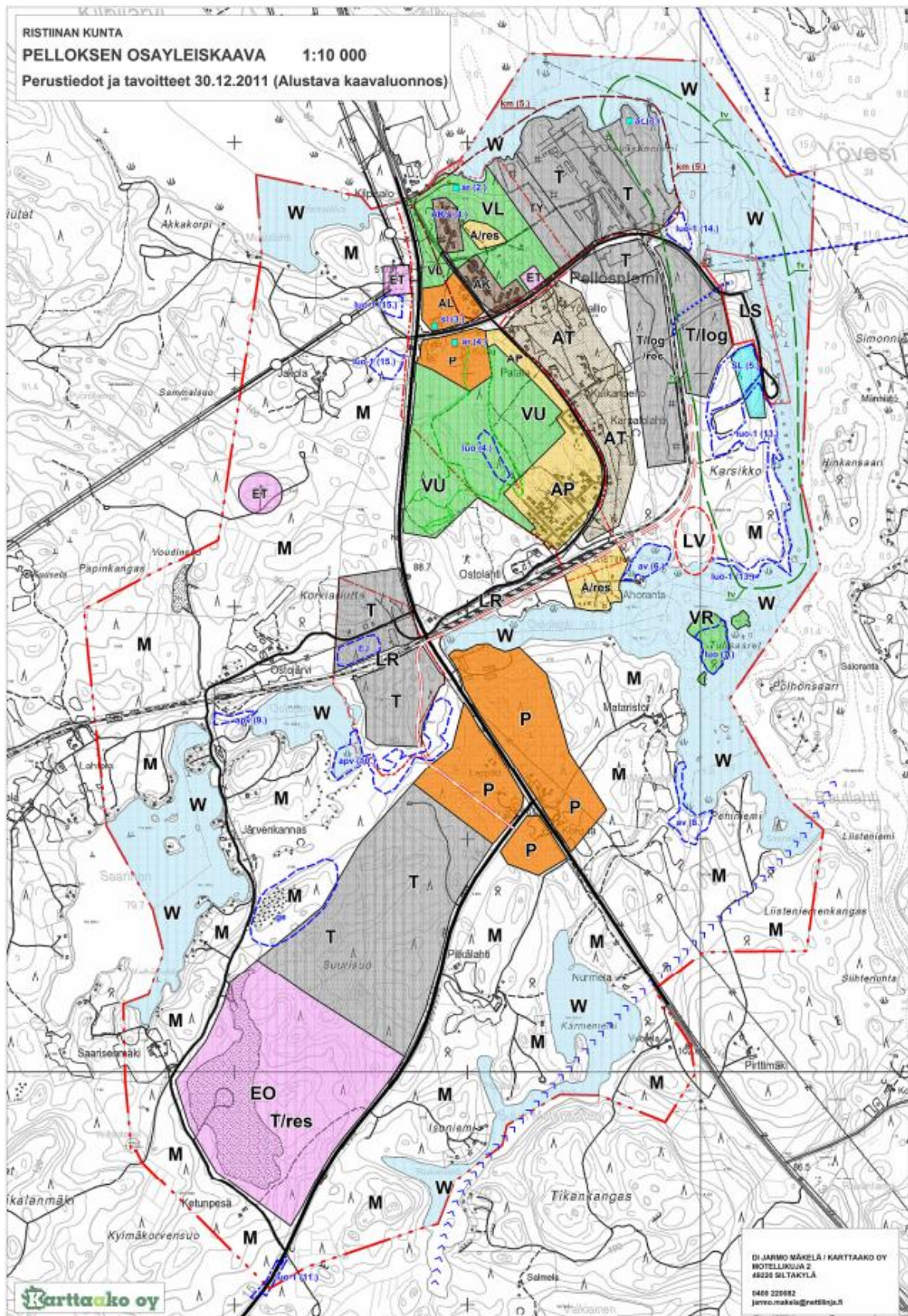
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Approximate translations of the land use plan markings

A	residential area	SL	nature conservation area
AK	apartment building dominating residential area	sl	natural monument
AP	detached house dominating residential area	luo-1	highly important area in terms of nature conservation
AT	village area	luo	important area in terms of nature conservation
AL	residential, trading and office area	apv	valuable minor water body
P	service area	av	valuable water body of its vegetation and fauna
T/log	area for bio-logistic centre	ge	valuable esker or other geological formation
T	industrial and warehouse area	ar	valuable building in terms of cultural history and/or environment
TY	industrial and warehouse area, where the environment sets special requirements	XX/s	area in which the environment is restored
XX/res	reserved area		
VL	recreation area		
VU	area for sports and recreational services		
VR	hiking area		
LR	railway traffic area	km	the cultural landscape of Pellosniemi plant community
LS	dockland / harbour area		
LV	boat-shore	vt	main road
ET	urban services maintenance area	yt/kk	collecting road
EO	land extraction area	yt	new collecting road
			new railroad
			recreation route
			sea lane
			connection need of channel
			power line
			area suitable for wind power production
			the planning area boundary
			the boundary of current town plan
M	agriculture and forestry dominated area		
W	water area		